POWER APPLIED TO PURPOSE:

Environmental Control and the Shape of Modern Architecture

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ABSTRACT

The idea is developed that environmental control systems -- lighting, heating, ventilation and acoustics -- are elements of architectural meaning with strong links to the shape of buildings. The resulting architecture of the well-tempered environment is aesthetic and semantic as well as functional and technological. Lyrical and technical elements of well-tempered architecture are examined and the origin of environmental tempering in Western culture is traced. The study begins with classical Greek and Roman examples, continuing with folk traditions and the development of the science of architecture. In each instance, building types are described which illustrate the impact of environmental tempering techniques and functions on the shape of architecture. Classical examples include the Roman villa, bath and theatre. Later building types are prisons, hospitals, factories, theatres and galleries. Thus, a repertoire of climatically responsive forms is examined.

The idiom is illustrated during the Modern era by the designs of four architects -- Frank Lloyd Wright, Le Corbusier, Alvar Aalto and Louis I. Kahn. Their works mark a zenith in the integration of architectural form with environmental tempering.

The final chapter surveys the architecture of environmental tempering since the Modern Movement, including Regionalist, Late-Modernist, High-Tech and Post-Modernist examples. The conclusion proposes a definition of an architecture based on the art and science of environmental tempering .

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INTRODUCTION

In this work I will explore a single protean idea — the relationship of environmental control systems to the shape of architecture. My thesis is based on the following propositions:

> 1 . Environmental control systems -- lighting, heating, ventilation, acoustics — have the power to give shape to buildings.
>
> 2. 'Well-tempering' has aesthetic and semantic as well as functional and technological meaning. Both art and science play a role in the design of well-tempered environments.
>
> 3. The origin of the form and symbolism of the well-tempered environment in modern architecture can be traced to classical times and to the beginning of the tradition of designing spaces which modify the climate to achieve comfort and delight.

Part of my thesis, and the first thing to notice about works which illustrate this point, is that the architecture of the well- tempered environment is not always purely functional; rather, environmental function inhabits these works as an 'element.' These elements or units of meaning can be traced to certain historic prototypes.

The architecture of successful environmental management seems neither accidental, nor necessarily the result of the advent of technology, but rather it has developed as the result of a tradition of systematic empirical research and discovery of cultural interpretations, giving forms which are proper to the environmental propositions being made. The architecture of the well-tempered environment seems to transcend formal definitions of architectural style, in the sense that it can give architectonic shape to the building envelope seemingly independent of particular stylistic constraints.

Architectural form derived from the act of environmental tempering can be detected in vernacular architecture as well as in specific works of individual architects such as Soane, Perret, Gropius, Dudok, Fuller, Mendelsohn, Rogers, and Stirling. The expression of the genre seems to reach its zenith, however in the works of Wright, Kahn, Le Corbusier and Aalto, whose works changed the 'look' of architecture on an international scale. In each of the designs which illustrate the thesis can be found a single statement or a repertoire of forms for climate modification which are technically based and semantically rich. Some of these elements — words or phrases — which express environmental function, are visually more powerful than others. In some inconceivable spot where the vectors of these designs intersect, there lies the architecture of pure environmental symbolism and function.

Visual power is not always directly related to technical or functional efficiency and aberrations occur in the application of the 'language' of environmental tempering. For example: the presence of brise soleil on the blank north facades of some buildings for purely aesthetic reasons. Carried to the extreme, the International Style carried architectural form away from local climatic and cultural determinants and in doing so lost the power to temper the climate to the benefit of the user. These transpositions of intended usage demonstrate the sometimes arbitrary nature of an environmental control system as an architectural sign, but nevertheless remind us of the symbolic power of an element of environmental control, even though the designer may have lost sight of its original function.

The discovery, invention and application of technological knowledge and devices in the history of environmental tempering is not a static and ideal world of intellectual pursuit. There are many loose and frayed ends:

the architects of the genre have not been consistent in their expressions and prototypes vary in purity of intent. Therefore, the path of this essay spirals out from a single issue to take in a great deal of territory. However, it attempts to be faithful to its subject, which has a similarly centrifugal lifeline.

1. Origins of Environmental Tempering

> If our designs . . . are to be correct, we must at the outset take note of the countries and climates in which they are built . . . . Thus we may amend by art what nature, if left to herself, would mar.
>
> Vitruvius: Book VI, Chapter 1

> It's a great pity that the Greeks didn't have glass . . . because if they had we wouldn't have to do any thinking even now.
>
> Frank Lloyd Wright, 1949

Architecture in classical times, in addition to achieving a balance between climate, technology and comfort, was also capable of delighting the senses. Houses in the Roman age were surprisingly well equipped with the means for providing comfort. According to Gloag, even the more modest country houses of Roman Britain were commodious and comfortable, with central heating, running water, latrines, baths and competent drainage. [Gloag, 1977, p 110.] Since then, the quest for comfortable and stimulating spaces matched to their climatic setting has continued in spite of many changes in the style and fashion of tempering the environment. The modern derivation of form through a conscious use of the elements of environmental tempering by Wright, Le Corbusier, Aalto and Kahn, could only have happened after centuries of collective experience in the shaping of space by climatic constraints through the application of available technology. The beginning of this progression is steeped in the Greek tradition of natural philosophy and the discovery of new methods by the Romans.

The environmental tempering of the Greeks and Romans, like their literature, is part of the common aesthetic inheritance of Europe. There is perhaps more to be learned from Rome than from Greece, since with the exception of Herodotus, the Greek writers show little interest in the techniques by which the glories of their architecture were produced. It might be imagined that the lack of attention to environmental tempering in Egyptian and Greek architecture might have been due not only to a lack of technical skill, but also to a lack of interest on the part of the early cultures and religions in interior spaces, due to the warm climate which encouraged outdoor living.[Cowan, 1977, p 5.]

The writings of Xenophon (428-354 B.C.) give insight into Greek attitudes towards comfort in the dwelling and the means for achieving it, for example:

> When he [Socrates] said about houses that beauty and utility were the same, he was giving a lesson in the art of building houses as they ought to be. He approached the problem thus:
>
> 'Is it not true that to have the right house it should be both useful and pleasant to live in?'
>
> And this being admitted: 'Is it pleasant,' he asked, 'to have it cool in summer and warm in winter?'
>
> And when they agreed with this also; 'Now in houses with a southern exposure, the sun's rays penetrate the porticoes in winter but in summer being less inclined, they afford us shade. If then, this is the best arrangement, we should build the south side loftier to get the winter sun, and the north side lower to keep out the cold winds.' [Xenophon, Memorabilia, Chapter 8]

In ancient Greece, the concept of climate and its effect on the health was characterised by a deification of the climatic elements of wind, sun and rain. The idea of remaining healthy by living in harmony with one's climatic environment had its origins in the mythical Greek physician Asclepius, whose daughters, Hygeia and Panacea symbolised two radically different approaches to healthy living. Hygeia was one of the manifestations of Athena, patron of the arts and crafts and goddess of wisdom. Concerned more with the prevention of disease and the maintenance of health than with the treatment of disease, she symbolised the belief that good health was achieved by living within the golden rule and according to the laws of reason.

Interest in climate and its effect on health was expressed as early as the 4th century B.C. by Hippocrates of Cos (c. 460-375 B.C.), often called the Father of Medicine. His philosophy was based on the belief that diseases are not caused by capricious gods or irrational forces, but that they constitute natural phenomena which behave according to natural laws. In addition to the mythical Hygeia, Hippocrates was influenced by Ionian physicists and by Empedocles's holistic theories. Contemporary schools of hygiene, which emphasise the prevention of disease in the community through healthy social practices, are derived from these origins. Classical descriptions such as 'unhealthy site' or 'unhealthy weather' have been preserved in modern thought.

An important part of Hippocrates's medical doctrine was based on the need to understand nature in order to comprehend the body and the soul of man. He also believed that an understanding of meteorology was necessary in order to become a successful physician. In his treatise, <u>On Airs, Waters, and Places,</u> Hippocrates discussed different climates, the effect of these climates on the health of the inhabitants, and the diseases prevalent in localities characterised by their exposure to particular winds.

Hippocrates made a number of points which are related to the modern concept of comfort and climate, among them:

1. The well-being of man is influenced by all environmental factors: The quality of air, water and food and the general living habits; the sun, the winds and the site.

2. Mind and body cannot function independently: Health means a healthy mind in a healthy body. This can be achieved only by living in accordance and equilibrium with natural laws. Good health is an expression of harmony with the environment.

Aristotle (384-322 B.C.) wrote the oldest comprehensive treatise on the subject of meteorology, Meteorologica. This work became the primary reference on weather theory for the next 2,000 years. [Zinszer, 1944, p 261.] His wind classification scheme was based on a meteorological theory of the power of the sun to drive the winds. Aristotle used astronomical directions, such as equinoctial sunrise, winter sunset, midday sun, etc., with the compass divided into either eight or twelve equal sectors to indicate the directions of the various winds (Fig. 1.1). In Aristotle's philosophy, Nature was reduced to four fundamental divisions: The Hot, The Cold, The Dry, and The Moist.

Theophrastus (370-288 B.C.), a pupil of both Plato and Aristotle, continued the development of the climatic concepts put forth by his teachers in his two works, On Winds and, On the Signs of Rain, Winds, Storms and Fair Weather. His analytical description of the properties of winds is extended to the modification by the wind of the microclimate of spaces in the vicinity of the building; to wind turbulence and to the draughts which occur in enclosures. He also described the physiological and psychological interactions between people and the winds. He described the influence of climate by showing how it transformed the life and activities of people. The authority of Theophrastus and the other the Greek scientists, Ptolemy, Hippocrates, and Aristotle, remained undisputed well into the 17th century.

Open spaces had a strong significance for the Greeks. The Greek Hippodamos wrote a work on town planning as early as the 5th century B.C. The agora for instance, was nothing more than an open space, usually in the centre of the Greek town, which incorporated political, social, economic and cultural functions. Its performance was regulated partly by climatic conditions. The political and economic functions of the agora diminished in its later forms in favour of the social and cultural activities found in the plaza, campo, piazza and platia in Latin countries.

The Hellenistic open spaces as distinct from the ancient Greek ones were characterised by a different organisation. Widening of streets took place after the 3rd century B.C. as a by-product of wheeled transportation and processional requirements for military and religious ceremonies. The desire for light and air resulted in the building of stoas which gave shade from the mediterranean sun. Mumford points out that the stoa 'became common in Hellenistic cities, with their general effort to improve urban comfort.' [Mumford, 1966, p 226.]

The Golden Age of Greek science ended during the 1st century B.C. with the Roman dominance of the eastern Mediterranean. To the Romans, the science of meteorology and building techniques was important mostly for its practical applications. In Roman architecture, the focus was re-directed towards the interior of a building, partly as a result of structural and technical discoveries. The dome and the barrel vault allowed perforations to admit light and air. The discovery of glass and the invention of operable devices gave more precision to the tempering of light and air.

The three Roman commentators most important to the history of architectural science and environmental effects were Vitruvius Pollio (1st century B.C.), Secundus Pliny -- Pliny the elder -- (A.D. 23-79) and Lucius Seneca (3 B.C.-A.D. 65). For details of building methods and an account of the importance of climate in the design of comfortable spaces, we are largely dependent upon Vitruvius. In The Ten Books of Architecture, he stressed the importance of climatic determinants in site planning, the orientation of streets and buildings and the location of rooms in dwellings in order to achieve maximum comfort and hygiene. An example of public building which demonstrated climatic knowledge for a practical use is still standing; the Tower of the Winds in Athens. It is shaped by its function of reporting the time and indicating the direction of the winds (Fig. 1.2).[Stuart, p 27.] Vitruvius described the tower with utmost precision:

> Andronicus of Cyrrhus . . . built the marble octagonal tower in Athens. On the several sides of the octagon he executed reliefs representing the several winds, each facing the point from which it blows; and on top of the tower he set a conical shaped piece of marble and on this a bronze Triton with a rod outstretched in its right hand. It was so contrived as to go round with the wind, always stopping to face the breeze and holding its rod as a pointer directly over the representation of the wind that was blowing.

Beneath the allegorical figures representing the winds on each face of the tower are traced sun dials. Vitruvius describes the origins and configurations of water clocks and sundials -- even a sundial for travellers -- in his work.[Vitruvius p 273.] The sun dials on the Tower of the Winds have silently indicated the time each day for over 2,000 years, a mute testimony to the sophisticated knowledge of solar mechanics practiced by the ancients. A clepsydra or water-clock, carefully channelled in the original floor, was found when the tower was excavated by Stuart in the 19th century, leading Delambre to describe the tower as 'the most curious existing monument of the practical gnomonics of antiquity.' [Stuart and Revett, 1898, p 28.]

The application of architectural theory also has a place in Vitruvius's writing. Having defined the winds, he directs the skillful designer in what to do with this knowledge. He proposed rules for orientation:

> Then let the directions of your streets and alleys be laid down on the lines of division between the quarters of two winds. On this principle of arrangement the disagreeable force of the winds will be shut out from dwellings and lines of houses. For if the streets run full in the face of the winds, their constant blasts rushing in from the open country, and then confined by narrow alleys, will sweep through them with great violence.
>
> The lines of houses must therefore be directed away from the quarters from which the winds blow, so that as they come in they may strike against the angles of the blocks and their force thus be broken and dispersed. [Vitruvius, p 27.]

The choice of a new Roman town site and its layout required the establishment of a cosmic ideogram of the town which took into account the proper location and orientation of the elements and the axes of the town. In the town Augusta Raurica, 44 B.C., the layout of the streets is rotated 36 degrees from the cardinal north, so that on the winter solstice the sun shines down the streets on rising and setting.

The Ten Books of Architecture was both a text in architectural theory and a guide to architectural practice. It represented the sum of architectural knowledge about the application of technology in the design of buildings which brought both comfort and delight.

Ancient Definition of Comfort

The sensation of feeling comfortable is affected by a broad range of physical and psychological variables over which the built environment exercises control, partially through the fulfillment of cultural expectations. Before an understanding can be reached of environmental conditions leading to comfort, knowledge of the cultural consensus which defines comfort is necessary. The building can be thought of as a filter between the external environment or climate and the comfort needs of the user within. The function of shelter in this regard is to extend the range of places on the earth's surface where human activities can take place without distraction from the climate. Given a reasonable climate with adequate natural resources, the human being can attend to the primary physiological needs for survival -- breathing, eating and drinking. Creating and maintaining correct temperature, light and sound conditions for comfort and performance of required tasks becomes in the strictest sense the function of the architectural environment.

By making the climate more even, the biological function of sleeping, working and playing are made easy where otherwise they might not be. The human, in common with other warm-blooded animals, can adapt physiologically and activities can take place over a fairly wide range of environmental conditions; however, human comfort cannot be defined merely in terms of homogeneous conditions of constant temperature, light and sound. To satisfy, there must be interest and variation in environmental tempering.

Interesting and varied environments have a psychological and cultural basis which can be found in both literary references and in the living record provided by vernacular architecture and folk traditions. In literature, early references emphasised the importance of shelter in providing comfort. Plato records the dialogue between Aristippus and Socrates, in which Socrates said:

> To summarise, the most pleasurable and the most beautiful house is that in which the owner can find pleasant retreat in all seasons . . . .

It is interesting to compare Socrates's prescription for beautiful architecture with another one from Roman times, namely that more comprehensive and widely quoted definition of Vitruvius, which is familiar to most English-speaking readers in Sir Henry Wotton's version: 'Well building hath three conditions: Commoditie, firmenes and Delight.' Vitruvius was careful to point out that delight was far more than merely a visual matter; good building would also help keep us warm in winter, cool in summer, provide us with good acoustics, and so on.

The Stoic philosopher, Seneca, was an early chronicler of the search for environmental comfort. A Spanish Roman, he was tutor to Nero in A.D. 49. When Nero succeeded as Emperor in 54, Seneca became consul and virtual prime minister. In his collection of Letters, he raises the issue of technological and natural response to human needs and the quest for luxury:

> Nature did not will people to be harassed. Whatever she made exigent she supplied us with.
>
> 'Cold is intolerable to a body unclothed.'
>
> What of that? Cannot pelts of game and other animals provide abundant protection from cold? Do not many tribes shield their bodies with bark? Are not birds' feathers sewn together to serve as clothing?

'But a thicker shelter is wanted to ward off the heat of the summer sun.'

And what of that? . . . Have not ordinary men woven reed mats together by hand and smeared them over with common mud and then roofed them over with stalks or other thatch so that the pitch carried the rains off, and so kept snug through the winter? Do not all peoples shelter in dugouts when the torrid sun leaves them no solid protection against heat except the arid earth itself?

Nature was not so grudging; when she gave other creatures an easy way of life she did not make it impossible for man to live without a host of appliances. . . Housing, shelter, physical comfort, victuals, the things which have now been made into an enormous enterprise, where easily available gratis and could be obtained with slight effort.

The limit was set by the need; it is we who have made those things costly and admired and the object of intense and ingenious pursuit. Nature suffices for her own requirements, but luxury has defected from Nature . . . At first luxury began to crave superfluities, and then abnormalities, and in the end enslaved soul to body and compelled its abject obedience to the body's lusts . . . the natural measure which limited desires by essential requirements has retreated; to desire a mere sufficiency is now a mark of boorishness. [Seneca, p 229,230.]

However, in spite of the warnings of some Roman philosophers against the excesses of technology, remarkable advances in the control of heat, light and air were made and found application throughout the empire.

Roman Heating Systems

The Greeks had used a simple arrangement for fire, which symbolised their spartan approach to comfort and environmental control.[Forbes, p 29.] By placing the fuel in a confined vessel on a tripod over the fire-bed or by lifting the fire in a semi-enclosed container which was pierced by holes in its bottom, the Romans achieved a better regulation of combustion, with the space below the grate or container serving as the induced draught chamber. This became the rudimentary stove (Fig. 1.3). But the successful operation of the stove in an enclosed space required the proper arrangement of room ventilation and the evolution of the chimney. In Europe, there is no record of stoves in common use before 1400, even though the development of the chimney had begun in the Roman hypocausts a millenium earlier. The hypocausts, however, were used primarily for public buildings and larger villas; smaller homes for centuries continued to be heated by open-hearth fires, portable braziers or fire-pots.

In addition to the braziers used for space heating and sometimes for cooking, there were pottery and bronze vessels for heating water, examples of which survive at Pompeii. In these devices the water was contained around the combustion chamber or around the smoke flue and the heat was transferred through the wall of the vessel to the liquid (Fig. 1.4).

Glass for Environmental Tempering

As important as the development of heating systems, which required constant replenishment with fuel, was the discovery and widespread use of glass in the Roman villa and bath. The earliest Roman window glass was 3 to 6 mm thick, pale blue or sea-green in tint and sometimes brownish.[Butti, 1980, p 7.] The oldest window pane in the Forum of Pompeii is a small, 13 mm thick, round glass disk in a bronze frame. Such glass has been found fitted in a building dating to 60 B.C. The central baths of Pompeii which were only partially finished, had windows of 200 x 300 cm in measurement. Similar large windows were found in the villas of the rich in that region. In Ostia, where some of the most important baths are to be found, large windows with marble lattice-work existed at about the same time. In contrast to the inward-looking Pompeiian house, it was the widespread adoption of window glass which enabled many of the individual rooms at Ostia to be lit from the outside.[Ward-Perkins, 1981, p 193.] In the thermae in the Forum at Herculaneum, examples of such panes have also been found.[Mau, 1900, p 187, and Formige, 1934, p 82.] The caldarium of the 1st century Roman baths with their much larger windows usually faced either south or east to profit from the sun's rays. Documentation as well as building remains point to these spaces as being early examples of solar heated public architecture.[Thatcher, 1956, p 167] In the large houses of Italy, planned for ease and pleasure, the window became the frame for a view. Pliny, who described the manufacture of glass in the 1st century by the fusion of sand and soda in an open fire writes about his Laurentine villa in a letter to Gallus:

> . . . a roomy bedroom, then a smaller one, with one window to let in the dawn, another to hold the sunset; with a view too of the sea below -- further off, certainly, but safer.[Newton, 1921]

This translation is significant for the last two words, 'but safer,' which recall an early apprehension -- a last breath of primeval terror of the elements which we have forgotten today but from which we were first emancipated by the Greeks and Romans.[Atkinson, 1926, p 319.] Translucent glass would have obscured the view from such carefully placed windows; either they were unglazed, or else operable, or the glass was superior in quality to that used in the provincial villa houses.

Seneca also writes about the use of glass in his time, noting the recent arrival and proliferation of this technology:

Some things we know to have appeared only within our own

> memory; the use, for example, of glass windows which let in the full brilliance of day through a transparent pane, or the substructures of our baths and the pipes let into their walls to distribute heat and preserve an equal warmth above and below. [Seneca, 'Letter to Lucilius']

In even the more modest country houses of Roman Britain it is thought that the windows were glazed, with glass cast in small panes, cemented into place. [Lethaby, 1923, p 31-32.] By the 3rd and 4th centuries the manufacture of glass had obviously improved, and although the prevailing colour was still pale green -- due to its iron content -- the glass was clearer and approached more closely to modern window glass. [McGrath, 1961, p. 29-30.] By this time, the glass manufacturers of Rome had become so numerous that a section of the city was assigned to them. The Roman Emperor Alexander Severus, imposed a tax on glass manufacture in A.D. 220. Constantine (306-337) later remitted the tax. Lactantius, in 290 writes that 'our soul sees and distinguishes objects by the eyes of the body as through windows filled with glass.' Jerome in 331, speaks of sheets or plates of glass produced by casting on a large flat stone, the forerunner of modern glass manufacture. It was from these techniques and traditions that window panes came, contributing to the Roman initiation of great innovations in the concept of interior space.

<u>Environmental Tempering and Architectural Form</u>

Classical beginnings of the application of technology in order to achieve environmental effects are best illustrated by three building types -- the villa, the public bath and the theatre. These were the first examples of an architecture which derived its form from environmental function. For the purposes of the present study, these prototypes should be understood as works of architecture as well as instruments for the application of available technology based both on cultural understanding and on scientific knowledge of climate and comfort. Their development can be compared in importance with the evolution of factory, hospital prison and theatre design during the Industrial Revolution and its subsequent influence on the shape of modern architecture.

The Villa

The most striking villa of Rome was Nero's Golden House, A.D. 64-68, which, with its astonishingly sophisticated management of interior climate, was the prototypical architecture of the well-tempered environment (Fig. 1.5). The central octagonal hall in the Golden House was the first recorded example of a spatial innovation in which light gave form to space (Fig. 1.6).[Ward-Perkins, 1981, p. 100; Boethius, 1960, p 103.]

To understand fully the place of this house in the context of building technology, we can look for help from Vitruvius. He had delineated some of the rules which permitted designs to achieve the level of sophisticated environmental tempering which was displayed in Nero's Villa. First, he describes the importance of taking into account the climatic differences between various regions and sites:

> If our designs for private houses are to be correct, we must at the outset take note of the countries and climates in which they are built. One style of house seems appropriate to build in Egypt, another in Spain, a different kind in Pontus, one still different in Rome, and so on with lands and countries of other characteristics . . . Thus we may amend by art what nature, if left to herself, would mar.

Next, the layout and orientation of the building itself in relation to the climate:

> The Proper Exposures of the Different rooms: We shall next explain how the special purposes of different rooms require

> different exposures, suited to convenience and to the quarters of the sky. Winter dining rooms and bathrooms should have a southwestern exposure, for the reason that they need the evening light, and also because the setting sun, facing them in all its splendour but with abated heat, lends a gentler warmth to that quarter in the evening.
>
> Bedrooms and libraries ought to have an eastern exposure, because their purposes require the morning light, and also because books in such libraries will not decay . . . Dining rooms for Spring and Autumn to the east; Summer dining rooms to the north . . . for the reason that it is unexposed to the sun's course, and hence it always keeps cool, and makes the use of the rooms both healthy and agreeable. Similarly with picture galleries, embroiderers' work rooms, and painters' studios, in order that the fixed light may permit the colours used in their work to last with qualities unchanged.

As for the natural lighting of rooms in dense urban settings, there is already some recognition of the importance of a clear 'window' or opening directed towards higher elevations of the sky dome -- an increased sky component of daylighting, as it would be known today:

> We must take care that all buildings are well lighted, but this is obviously an easier matter with those which are on country estates, because there can be no neighbour's wall to interfere, whereas in town high party walls or limited space obstruct the light and make them dark. Hence we must apply the following test in this matter:
>
> On the side from which the light should be obtained let a line be stretched from the top of the wall that seems to obstruct the light to the point at which it ought to be introduced, and if a considerable space of open sky can be seen when one looks up above that line, there will be no obstruction to the light in that situation. But if there are timbers in the way, or lintels, or upper stories, then, make the opening higher up and introduce the light in this way. And as a general rule, we must arrange so as to leave places for windows on all sides on which a clear view of the sky can be had, for this will make our buildings light.

The octagonal room in Nero's Golden House embodied the Roman knowledge of climate and comfort which permitted a shift of emphasis from the masses and solids typical of Greek architecture to an architecture of voids and light. It also reflected a change in attitudes toward the control of nature through the use of technology. Nero's villa was essentially an architecture of interior space, in which the technical manipulation of light, the acoustical properties of running water and other environmental amenities provided its unique qualities. Entry to the main domed space -- with its giant oculus symbolising the sun -- required passage through corridors mysteriously lit by openings provided above the outer curvature of the dome and hidden from view.

On entering, the interior of the octagonal room delighted the senses with its barrage of visual and auditory experiences. Water cascaded noisily down into the room along a steeply stepped artificial channel. There were false windows, painted with landscape scenes, illuminated from behind. [Billington, 1982, p 397.] There was a revolving spherical ceiling which possibly functioned in the evenings as a planetarium, turned by running water -- or by draft animals -- in the basement. [Boethius, p 103.]

Nero's guests could feast in nearby rooms which had ceilings of fretted ivory and, according to Seneca, 'assorted . . . coffers [fitted] so ingeniously that one pattern follows close upon another and the roof changes as often as the courses,' and in which there was 'a process for spraying saffron from hidden pipes.' Or they could bathe in sulphur-water piped from Tivoli while contemplating walls inlaid with mother of pearl and gems. Vitruvius described one of the techniques for controlling temperature, light and humidity in the domed bathing spaces (Fig. 1.7):

> [There is] an aperture left in the middle of the dome with a bronze disc hanging from it by chains. By raising and lowering it, the temperature . . . can be regulated.

Such opulence and the growing dependence on technology evoked in Seneca a wistfulness for the simple life; he wished that man could

> . . . demonstrate to himself and others that . . . we can live without the marble-worker and engineer, that we can be clothed without the silk trade, that we can have the necessities we require if we are content with what earth carries on its surface. Necessities require little care; it is luxury that costs labour. Follow Nature and you will not wish for artificers.

This early plea for the rejection of technology in favour of natural methods was a reflection of Seneca's Stoic philosophy, but it is a familiar refrain to the present day.

The Roman Baths

Emerging at about the same time as Nero's Golden House was a new building type, the public bath, which took the Roman spatial discoveries and environmental technology to full realisation at a monumental scale. The architecture of the villa had nurtured the technology necessary for the development of environments for bathing. The heating, plumbing and lighting systems for the smaller private baths were simple in concept and fairly easy to operate, but they could exert various and considerable influences on the physical ambience of the bathers. Whilst the means of changing the air and water temperatures were not very complicated, a variety of results was accomplished by inter-relating the heat sources, the flow of air and water and the exposure to light in a number of different ways. At a diminished scale the smaller private baths found in the villas could produce the sequence of sensory experiences found in the larger public baths. At this early date it was possible to control the absence or presence of water, light, heat, air and sound and the volume of any or all in any given room. This was accomplished by the proper design of room orientation, the shape and location of the various windows, oculi and other openings along with the locations of the furnaces, plumbing and the fountains. Environmental control systems had become architectonic in the sense that they contributed the qualities of order, balance and unity to the architecture of the bath. [MacDonald, p. 16.]

Private baths, while lacking the sense of scale of their monumental public counterparts, became a sensory and spatial experience which reached its zenith in the small baths of Hadrian's Villa at Tivoli (c. A.D. 120), which demonstrated some of the most exciting and unusual architectural arrangements of the time (Fig. 1.8). [Boethius, p. 115.]

The same technology that was used for the baths was also used to extend the growing season of plants, and it was here that hothouses and 'forcing houses' got their start. With the advent of the elements of the Roman hypocaust heating system -- developed for the bathing environment -- we begin to see the architectonic interaction of environmental management systems in such a way that structure, building envelope, and spatial arrangements become unified with heating, ventilation and water distribution systems. Not again until the 17th century European hothouses were the elements of environmental tempering to operate in such harmony.

As in the villa, the development of new technology made everything which the baths sought to be possible. The use of copper water heaters, ducted, radiant heating systems as well as south-facing glass for solar heating became common and widespread. [Butti, 1980; Thatcher, 1956, p 167-264.] Just as important as the technology, the cultural environment seemed ready to accept the new inventions surrounding the great public baths which offered so much more to the Roman way of life than the previous Greek laconicum or sweat bath. The diffusion of this essentially new building type across the Empire was both rapid and pervasive. The new public baths were not universally praised, however. The fact that cleanliness was next to decadence was a view commonly expressed by the Romans themselves. Tacitus (A.D. 55-120) was of the opinion that baths, porticoes and dinner parties represented the bad side of Romanisation, in contrast with fine public and private building and sound education. Luxurious bathing places, together with the habit of daily baths, were, in the view of the moralists, a hedonistic contamination. In simpler and better days Romans had bathed rarely, and in uninspired surroundings.[Balsdon, 1969, p 27, 32.]

When public baths were first introduced in the 2nd century B.C., they were small, dark places for washing (Fig. 1.9). Seneca gives us the benefit of his descriptions of the interiors of both public and private baths of his time. He compares the rather dreary environmental conditions in Scipio's traditional villa to others. He describes the inside of the villa:

> There was a cramped bath, quite unlit, after the old fashion; our ancestors thought a hot bath must be dark . . . in this cranny the terror of Carthage, whom Rome had to thank that the Gallic sack was not repeated, used to wash down a body tired out by field chores . . . . Who would tolerate such bathing nowadays? A man thinks himself poor and slovenly if his walls are not shiny with large and costly mirrors . . . if there is no room enclosed in glass; . . . when the spigots for discharging the water are not silver.
>
> So far I have been speaking of ordinary establishments; what shall I say when I come to the freedmen's baths? What a quantity of statuary, what a quantity of columns that hold nothing up but are planted as extravagant ornaments! What a quantity of water, arranged to produce a series of crashing falls!

Seneca waxes passionately on the subject of bathing environments as he continues:

> In this bath of Scipio's there are not windows but chinks cut out of the masonry to admit light without weakening the structure. Nowadays they call baths moth-dens if they are not planned to get sun all day through spacious windows unless they can bathe and tan simultaneously, unless they have a view of the countryside and the sea from their tubs . . . . Once baths were few and had no elegant trimmings . . . There were no showers in those days, nor a continuous stream as from a hot spring, and they didn't think it mattered how crystal the water to leave their dirt in was . . . .

Seneca is not beyond moody complaining about the failures of environmental control in the bath which was followed by nostalgia for earlier times. He revealed the personal bathing habits of the time:

> Romans used to enter the resorts which catered to the populace and insist upon cleanliness and a moderate and healthy temperature, not the blazing heat newly introduced, so great indeed that a slave convicted of crime should be bathed alive! Now I think a man might as well say, 'The bath is on fire,' as, 'The bath is warm.'
>
> Nowadays some people write Scipio down a yokel because he let no daylight into his sweat room, did not broil in a strong glare, or wait in his bath until he stewed . . . . If you must know, he didn't bathe every day. Writers who have recorded the manners of our old Romans tells us that they washed their arms and legs every day -- these, of course, they dirtied working -- and took a whole bath once a week.

The morphological development of the Roman bath from the simple forms of the Greeks to a public building of great magnitude with thermally graded, well-lit spaces having important social significance, depended on the confluence of three lines of technological development: 1. the structural possibilities of the concrete dome; 2. use of glass for admitting light and trapping heat, and; 3. the operation of an adjustable hot-air heating system with ducts and flues to direct the hot gases. These systems appeared together in the 1st century A.D. in baths such as the ones at Ostia Antica (Fig. 1.10).

Giedion writes of a room uncovered at Ostia whose southern side opens into a single span supported only by two marble pillars. The opening formed a wall of glass, making the entire space a winter sun bath. [Giedion, 1948, p 632.] He describes these buildings as having interiors flooded with light

> [which] poured through the great half-circle windows, with their two jambs. The tepidaria of the thermae are, so far as we know, the first monumental interiors into which full daylight could enter through exterior window apertures. [Giedion, 1948, p 632.]

An example of the use of interior light to maximum effect is shown in the manner in which the tiled mosaics were constructed. Great care was taken in the best mosaics to insure that the small _tesserae_ of coloured stone, marble and glass were not perfectly level and flat , since an uneven surface catches the light and reflects it in different ways according to the angle of incidence and the material used for the _tesserae_. This detail contributed to the sparkle and liveliness of the interiors found in the baths.

The Imperial bath was the first large building to submit to the form-generating power of the environmental control system. Partly because it was a new type, not burdened with the preconceptions of tradition, the baths were well-suited for becoming the most influential and important medium for the expression and dissemination of new concepts of environmental control. The Roman taste for public bathing as a social relaxation was an important factor in the development of these new forms. In Rome itself, these ideas took shape under the strong influence of contemporary bathing habits which the success of the buildings themselves did much to promote.

New methods and materials of construction made the development of the grand surprises in space defined by light possible -- vaulted concrete was a material ideally suited to the practical requirements of enclosure with the added possibility of openings for the exchange of light and air. The domes, which succeeded the dark and dangerous arches of wedge-shaped stones, were among Rome's greatest architectural triumphs. They were designed chiefly for garden buildings or the hot rooms of the baths, permitting diameters as great as 116 feet.

The largest of these buildings were no mere bathing establishments; they included art galleries and an assembly of halls and chambers in which people walked, sat, read, recited and were refreshed and entertained. They were places to which people who had the time to spare went to relax. The development of the form of the public bath with its interlocking spaces and environmental delivery systems, linked in a rational relationship with the building as a whole, took place over a relatively short 50 year period. The full range of spatial development can be traced from the early Baths of Titus (A.D. 80) -- located in Rome near Nero's Golden House -- to the Baths of Caracalla, 212-216, where the style reached its apotheosis in a monumental bath which could accommodate 2,000 people at once -- large enough today to dwarf even a production of Aida (Fig. 1.11).

In comparing the early and later plans, the developmental sequence of the organisation of spaces becomes evident. The major change over this period is the movement of the final cold water plunge of the bathing sequence, the frigidarium, from one end of the central axis to the centre of the whole complex, with vistas opening out from it to all directions. This is an arrangement which was presaged at a smaller scale by the octagonal room of the Golden House. Once this pattern had been fixed, the building type changed little from Rome to the provinces over the next two centuries.

Some idea of the quality of natural lighting coming from an apparently hidden source and the multiple vistas which created a deliberate sense of spatial ambivalence can be experienced today in what was once the frigidarium of the Baths of Diocletian, which has now been converted to the Church of S. Maria degli Angeli. Although the decoration and the purpose is different, the sense of volume, space and inspiration must approach that of the original.

The environmental possibilities at the time were chronicled by Vitruvius who devotes a chapter to the Baths. First, the selection of the site:

> In the first place, the warmest possible situation must be selected; that is, one which faces away from the north and northeast . . . .

> Next, attention to the orientation and location of the rooms with respect to one another, as well as the ordering of the environmental equipment, including adjacent heating and plumbing for maximum efficiency and heat recovery from the fuel (Fig. 1.12):

> We must also see to it that the hot bath rooms in the women's and men's departments adjoin each other, and are situated in the same quarter; for thus it will be possible that the same furnace should serve both of them and their fittings.

> Three bronze cauldrons are to be set over the furnace, one for hot, another for tepid, and the third for cold water, placed in such positions that the amount of water which flows out of the hot water cauldron may be replaced from that for tepid water, and in the same way the cauldron for tepid water may be supplied from that for cold. The arrangement must allow the semi-cylinders for the bath basins to be heated from the same furnace.

He describes the construction of the flues in great detail, the thermal and vapour barrier protection necessary in the hottest rooms, and the placement of equipment in each of the rooms with respect to their environmental function:

> Vaults in hot bath rooms will be more serviceable if they are doubled; for then the moisture from the heat will not be able to spoil the timber in the framework, but will merely circulate between the two vaults . . . . When the sun shines full upon the rounded part of it, the air, being shut up in the curved enclosure and unable to circulate, stays there and becomes heated . . . . the washbowl ought without fail to be placed under a window, so that the shadows of those who stand round it may not obstruct the light . . . .
>
> The Laconicum and other sweating baths must adjoin the tepid room, and their height to the bottom of the curved dome should be equal to their width. Let an aperture be left in the middle of the dome with a bronze disc hanging from it by chains. By raising and lowering it, the temperature of the sweating bath can be regulated. The chamber itself ought, as it seems, to be circular, so that the force of the fire and heat may spread evenly from the centre all round the circumference.

These principles of environmental control, which evolved over a relatively brief period and which were carefully described and passed along, contributed to the great functional and social success of enclosed spaces in the Roman villa and bath. One further development will be described; environmental control at the urban scale in the Roman theatre and other public gathering spaces.

Roman Theatre and Public Spaces

Vitruvius's writings on the application of acoustical principles showed a profound knowledge and understanding of the behaviour of sound waves. He describes the selection of a site for the theatre:

> pains must also be taken that the site be not a 'deaf' one, but one through which the voice can range with the greatest clearness. This can be brought about if a site is selected where there is no obstruction due to echo . . . .

His description of acoustic principles is poetic and remarkably accurate in technical detail:

> Voice is a flowing breath of air, perceptible to the hearing by contact. It moves in an endless number of circular rounds, like the innumerably increasing circular waves which appear when a stone is thrown into smooth water, and which keep on spreading indefinitely from the centre unless interrupted by narrow limits, or by some obstruction which prevents such waves from reaching their end in due formation. When they are interrupted by obstructions, the first waves, flowing back, break up the formation of those which follow.
>
> In the same manner the voice executes its movements in concentric circles; but while in the case of water the circles move horizontally on a plane surface, the voice not only proceeds horizontally, but also ascends vertically by regular stages . . . .

And from the first principles, he makes the leap to the derivation of architectural morphology:

> Hence the ancient architects, following in the footsteps of nature, perfected the ascending rows of seats in theatres from their investigations of the ascending voice, and, by means of the canonical theory of the mathematicians and that of the musicians, endeavored to make every voice uttered on the stage come with greater clearness and sweetness to the ears of the audience.
>
> For just as musical instruments are brought to perfection of clearness in the sound of their strings by means of bronze plates . . . so the ancients devised methods of increasing the power of the voice in theatres through the application of harmonics.

He goes on to describe in great detail the theory of harmonics and the construction of sounding vessels in the theatre for the amplification of the human voice.

> On this principle of arrangement, the voice, uttered from the stage as from a centre, and spreading and striking against the cavities of the different vessels, as it comes in contact with them, will be increased in clearness of sound, and will wake an harmonious note in unison with itself.

In addition to the interior effects achieved in the villa and the bath, environmental control of public spaces came about through a sophisticated knowledge of climate, especially the daily and seasonal path of the sun. Vitruvius detailed the relationships between the sun and buildings in Book IX. The design of sundials became the special technical province of the architect: He could design a sundial mounted on a surface oriented in any direction, such as the ones seen on the Tower of the Winds. The instruments which were used for such designs were the ancestors of the ones shown in a 16th century painting by Holbein (Fig. 1.13). The relationship the path of the sun and buildings is shown in a 16th century manual published in Venice (Fig. 1.14).

Techniques of solar shading and control were widely practiced, not only to achieve thermal comfort but also for special lighting effects in theatres and other public spaces. Shading was introduced at the dedication of the restored Temple of Jupiter on the Capitol in 69 B.C., when an awning or velarium was erected to protect spectators from the sun. [Pliny] In 23 B.C. the Emperor Augustus erected a great awning over the Forum for the whole summer, which demonstrated the borrowed technology of sail handling applied to the purpose of environmental control. This remarkable construction involved the use of tall central poles and a cumbersome tackle operated by a special detachment of sailors assigned to this duty from the Roman navy (Fig. 1.15).

During this time, the velarium came to be a regular fitting of the permanent theatres and of the amphitheatres, including the Colosseum. [Bieber, 1961, p 179.] Lucretius describes how the illusion of the theatre was increased by the artificial lighting which resulted from the colours of the awnings themselves:

> This is often done by yellow and red and purple awnings. When outspread in the public view over a great theatre upon posts and beams they tremble and flutter; for then they dye, and force to flutter in their own colour, the assembly in the great hollow below and all the display of the stage . . . . All within laughs in the flood of beauty, when the light of the day is thus confined.

Another way of using light and shadow which was known in the Greek theatre was the shadow play, a type of puppet theatre in which articulated figures are manipulated between a strong light and a translucent screen, so that the audience saw merely the shadows of the figures. [Taylor, 1970, p 253.]

Summary

The heritage of environmental tempering in Western architecture was born in early Greek and Roman attitudes toward thermal and visual comfort as determinants of health and well-being. By the end of the 2nd century A.D., sophisticated environmental control technology was linked to the shape of Roman architecture. The important architectural components of environmental control were found in three building types; the villa, the bath and the theatre. In these buildings, architectural means for tempering the environment were developed using devices such as the oculus, the window, solar shades and shaped spaces for the propagation of sound. During this time, the architectonic forces of lighting, heating and ventilation became important determinants of spatial quality, contributing to the overall effect of order, balance and unity. Classical architecture of the well-tempered environment achieved the synthesis of environmental function with architectural form.

2. Folk Traditions and New Discoveries

> Let all the principall chambers of Delight, All studies and Libraries, be towards the East: For the Morning is a friend to the Muses.
>
> --Sir Henry Wotton, 1624

Attitudes towards climate, hygiene, and human comfort during the Middle Ages were shaped by the Classical works transmitted by church scholars. [Singer, 1959, p 218.] From A.D. 400 to 1100, study of climate and comfort never completely ceased. One of the greatest of the church scholars was Bede the Venerable (c 673-735), the first Englishman to write on the weather. [Botley, 1935, p 346.] Among his scientific works was De Natura Rerum, written around A.D. 703 with chapters devoted to the atmosphere, wind, clouds, and lightning.

Medieval research in the natural and physical sciences was largely research in the library. Whenever the choice arose between going out to the field or to nature or back to the books, the cloistered scholar retreated to his books. Argument from authority outweighed experimental evidence. Before an understanding of the scientific basis of comfort and climate was to develop further, this supremacy had to be broken. The only Platonic work known in the Middle Ages was Chalcidius's translation of the Timaeus, which was the basis for Neoplatonic theology and metaphysics taught in the cathedral schools. In these teachings, light was regarded as the visible manifestation of God's presence and the means by which divine power energises the world of natural activity. This is the chief reason for the aesthetic importance of light in the church and the basis for the vigorous development of scientific optics in the 13th and 14th centuries, including the work of Roger Bacon, Robert Grosseteste and Dietrich of Freiberg. After Bacon, there was a 400 year lull until the appearance of the one man who ended an era of speculation about physical phenomena, Rene Descartes.

In addition to the writings of the scholars through the centuries, cultural values in climate and comfort were handed down from generation to generation. Folk traditions recorded through the centuries reveal the depth of the personal effect which the coming and going of the seasons had on the pattern of household relationships. For instance, the influence of climate on life in the South American colonies of Spain is evoked by Gabriel Garcia-Marquez:

> No one knew exactly when [Ursula] had begun to lose her sight. At first she thought it was a matter of a passing debility . . . but quite soon she began to realize that she was irrevocably sinking into the darkness, to a point where she never had a clear notion of the invention of the electric light, for when they put in the first bulbs she was only able to perceive the glow. Sometimes unforeseen accidents would happen. One afternoon when Amaranta was embroidering on the porch with the begonias, Ursula bumped into her.
>
> 'For heaven's sake,' Amaranta protested, 'watch where you're going.'
>
> 'It's your fault,' Ursula said, 'you're not sitting where you're supposed to.'
>
> She was sure of it. But that day she began to realize something; that with the passage of the year the sun imperceptibly changed position and those who sat on the porch had to change their position little by little without being aware of it. From then on Ursula had only to remember the date in order to know exactly where Amaranta was sitting. [Garcia-Marquez, 1970, p 251-253.]

The transition from summer to winter in the vernacular home was often accompanied by a configurational change in the layout of the house, the prototype for which is described in this account of life in early 19th century Spanish household:

> About the middle of October every house in Seville is in a complete bustle for two or three days. The lower summer apartments are stripped of their furniture, and every chair and table are removed to the opposite side of the court. This change of rooms, together with mats laid over the brick floors, thicker and warmer than those used in the warm season, is all the preparation against winter that is made in Spain.

In addition to the use of fire, which consumed scarce supplies of wood and filled early interiors with smoke, the harsh winter climates were endured with a modicum of comfort provided by the use of local, readily available materials, such as animal skins and straw. The use of straw as insulation was probably widespread in colder Central and Northern European climates. Some idea of the conditions of early workers during cold times is given in an account by Bernan in his History and Art of the Warming and Ventilating of Rooms and Buildings, published in 1845. He describes the first artificial climate as being the heat from the bodies of animals:

> In Normandy, where the cold is severe, and the firing expensive, the lacemakers to keep themselves warm and save fuel, agreed with some farmer who had cows in winter quarters, to be allowed to carry on their operations in the society of the milky mothers. The cows are tethered in a row, on one side of the apartment, and the lacemakers sit cross-legged on the ground on the other side with their feet buried in straw. The cattle being out afield by day, the women work all night; and numbers of their own rank resort to these cowhouses, and sit or lie down on the straw beside their sweethearts, and sing, tell stories, and say soft things to cheer them in their labours.

The modern, technological equivalent of this practise is the use of electric heat pumps which move heat from the stables to the living room on some English farms. Early ethnologists give us a scent of what life must have been like under the most basic comfort conditions -- the same conditions which Seneca had aspired to. Early reports reveal living conditions in the vernacular house which were a challenge to the sensibilities. Locally available building materials gave form to the task of climate modification. A hut is described, which is:

> built of stone or turf, about eight feet high with a flat roof...the walls are hung with skins, and the door is so low that he creeps on all fours to gain admittance. Here half a dozen families live together, each having its own portion of the hearth, with a trivet and lamp, over which are hung the kettles for cooking.
>
> The room is as hot as a bagnio; and the animal exhalations, the effluvia from the burning lamps fed with whale oil and from many sorts of raw meat, fat, and fish and other matters kept in and near their cottages, create such a smell, that it strikes one not accustomed to it to the very heart.

The primitive state of indoor air quality in 18th century Russia is described by the English pioneer of hot-house technology, John Loudon:

> On entering a Russian cottage, a stranger is almost suffocated with the horrible effluvia with which it is filled, and the effect on his lungs is such as to deprive him of the power of speech and that of standing upright. [Loudon, 1817, p 113.]

The least expensive solutions to comfort were the ones which required no fuel for operating energy. Harsh winter climates in combination with religious zealotry in the late 1700's led to the strange and discomforting episode of the Fraternity of the Penitents of Love. It was their object to show that the fire of their love could in winter produce the same effect as a fire of wood and charcoal, and in the middle of summer act like ice and snow:

> To prove this, the resolute knights and squires, dames and damsels, who had the hardihood to embrace this severe practice, clothed themselves during the heat of summer in

> the thickest mantles, lined with the warmest furs; The fire of their love kept them cool.
>
> In winter they dressed themselves in the thinnest and lightest stuffs that could be procured. Fires all winter were banished from their houses. The fire of their love made everything genial. Many perished by the inclemency of the weather and died martyrs to their enthusiastic profession.

The decline of the bath as an architectural form can be attributed to the rise of Christianity. The attitude of Christians toward cleanliness and comfort over the centuries is a parable which reveals the influence of fashion and style over the cultural and moral values which affect personal habits. The Church originally attacked the Roman habit of the bath on the ground that everything which brings worldly comfort or which makes the body more attractive tends towards sin. Dirt was to be desired, and the odour of sanctity became more and more penetrating. 'The purity of the body and its garments,' said St. Paul, 'means the impurity of the soul.' Lice were called the pearls of God and to be covered with them was the unquestioned mark of a holy man. There is an allegorical story of one monastery in the desert where the monks suffered greatly from want of drinking water. Fervent prayer of the abbot Theodosius at last produced a copious stream. However, some of the monks, tempted by the abundant supply, wavered from their old austerity, and persuaded the abbot to construct a bath using the water from the newfound stream. The bath was made. The monks enjoyed their ablutions only once however, whereupon the stream ceased to flow. Prayers, tears and fastings were in vain. A whole year passed. At last the abbot destroyed the bath which was the object of the Divine displeasure, and the waters flowed afresh. [Lecky, p 117-118.]

Modern Culture and Comfort

The design of spaces with contrasting experiences in light, temperature and sound is sought by many architects who would avoid monotonous, steady, non-stimulating environments. Contrasting values of light and temperature can affect comfort and performance in a positive way, but if taken too far can diminish performance and threaten survival. Exposure to conditions which are close to the limit of tolerance has provided scientists with information which illustrates what happens as we approach the extremes of cold or heat. By defining the limits to environmental conditions, we also understand better the factors affecting comfort and stimulation.

In the very coldest conditions, frostbite, snowblindness, skin damage, or undue loss of body heat occurs, resulting in hypothermic injury within the body. Immersion in very cold water may result in death in 7 to 15 minutes. In extremely cold conditions, metabolic heat becomes insufficient, and shivering becomes the only way of generating enough heat to maintain body temperature. Under these conditions, the skin becomes insensitive to pain, thermal contol is lost, and drowsiness and coma ensue.

The aborigines of Australia and the Yaghan Indians of Tierra del Fuego were known for their legendary ability to withstand cold, however, stories concerning these tribes sometimes became exaggerated. They may not have actually undergone the extremes of cold attributed to them, and in fact they protected themselves against extreme cold in the limited ways known to them. It is known that the aborigines slept between two fires on cold nights. The night is the coldest period in the desert because of intense radiation heat loss through the clear night sky. If these primitive people made it through the night, when sleep was necessary, they could survive the day when temperatures are higher.

Observations of the Pitjandjara tribe of Australian aborigines were made by a team of German scientists during the 1950's before they lost their adaptation to cold by wearing clothing. The custom of the Pitjandjara natives spending the night in the central Australian desert was to build a windbreak of eucalyptus and acacia branches. To the leeward of this they built two fires between which they would lie, either singly or two people back to back. This illustrates the fundamental difference between environmental aids to comfort of the structural type -- including clothing -- and the energy consuming alternative, of which the campfire is the archetype. According to Banham,

> an ideal tribe of noble rationalists would consider the amount of wood available, make an estimate of the probable weather for the night -- wet, windy, or cold -- and dispose of its timber resources accordingly. A real tribe, being the inheritors of ancestral cultural predispositions would do nothing of the sort, of course, and either make fire or build a shelter according to prescribed custom. [Banham, 1979, p 43.]

The Pitjandjarans found it necessary to stoke the fire between three and ten times during the night, depending on conditions, but otherwise they lay quietly, sometimes snoring in deference to the cold. The German physiologists attempted the same procedure. They lay naked between two fires and found that they had to stoke the fires from 11 to 14 times during the night and slept only fitfully during the intervals. They experienced a weird sensation of simultaneous perspiration and goose pimples as the fires heated one side of the body and the cold sky chilled the other parts; painful examples of radiant heat exchange with the environment.

On windless, cold nights, it was possible to sleep a little, but on windy nights conditions were nearly unbearable. Skin temperatures, deep body temperatures, and metabolic rates of the sleepers were measured. The skin temperatures were usually lower in the natives than in the scientists, but they all dropped to between 12° and 15° C. on the coldest extremities and went up to 45° C. on the side facing the fire whilst the air temperature was 0° C. These skin temperatures, which were commonplace to the natives were painful to the scientists. By contrast, when the scientists spent the cold nights in their lightweight sleeping bags, their skin temperatures remained above 33° C., even at their feet.

When no fires were used, and both natives and scientists spent the night nude in lightweight sleeping bags, the metabolic rates of the scientists fluctuated a great deal, whilst those of the natives remained nearly constant. The scientists were restless and shivering much of the night, and the natives lay motionless all night shivering only a little when they arose in the morning. The feet would cool down to 15° C. This was distressingly cold for the scientists, but it did not seem to disturb the natives. When the skin temperatures of Europeans drop to 19° C. , shivering usually begins. This pattern changes as cold-adaptation occurs. Cold adaptation had given the aborigines greater tolerance to chilling than Europeans, but they had modified their environment by the introduction of fire in the interest of comfort.

The mountains of Norway were the setting for another experiment in thermal comfort. Eight men volunteered to live and hike above the tree-line for six weeks during September and October, wearing light summer clothing. The air temperature at night fell to 0° C. and the men spent the night naked inside a single-blanket sleeping bag covered with a thin wind cover. At first the men were miserable, sleeping little at night, shivering much of the time, and thrashing about constantly. After about a week they were able to sleep through the night and remain warm from head to foot. The metabolic heat generated by these eight men increased as the result of their shivering, which eventually became compatible with sleep and rest after acclimatisation took place.

Tolerance to hot environments, is mediated by the evaporation of perspiration, which is the only means of losing heat when the air is at or above body temperature. At these temperatures, if the humidity rises to 100 percent, it becomes impossible to lose heat either by radiation or by evaporation. The only alternative is for the body temperature to rise due to the continuous heat being produced by metabolism, until the upper limit of body temperature is reached. The most famous illustration of the potentially lethal consequences of this is that of the Black Hole of Calcutta where 146 men were confined in a small cell meant for two persons. There were but two windows. A survivor left an account of the struggle for air:

> Within a few minutes after entrance every man was bathed in a wet perspiration and was searching for ways of escape from the stifling heat. Clothing was soon stripped off. Breathing became difficult. Thirst grew intolerable. Ungovernable confusion and turmoil and riot soon reigned. Men became delirious. But all efforts for relief were in vain, until at last bodily and mental agony was followed by stupor.

This tragedy remains as a drastic demonstration in human history of the bondage of man to the air that surrounds him.

Modern Concepts of Comfort

There are many examples today of buildings which deliver constant levels of environmental control. Government agencies and the professional societies of illuminating and heating engineers have devoted many years' work to the definition of comfort standards. However, human comfort cannot be defined in terms of homogeneous -- sometimes monotonous -- conditions of constant temperature, illumination and sound.

The investigation of sensory deprivation by John Lilly and others in the 1950's seems to support the notion that the kind of climatic variation which many architects seek in buildings on aesthetic grounds has a psychological and physiological basis. Lilly discovered that normal consciousness, perception and thought can be maintained only in a dynamic environment. His experiments showed that where sensory deprivation occurs, boredom, restlessness and lack of ability to concentrate often follow.

The original work of Lilly involved the use of a 'sensory deprivation tank,' which is now available in the U. S. as a kit to the individual amateur interested in exploring the limits of psychological tolerance. His tests were carried out in an insulated, enclosed tank containing water at 94.5° F., the temperature at which the subject feels neither hot nor cold. Most of the usual pressures on the body caused by gravity are lacking. The sound level is low; only one's breathing is heard. It is one of the most even and monotonous environments which it is possible to experience. Immediately on leaving this environment, Lilly's subjects wrote personal notes on their reactions. A few general phenomena were observed:

1. for the first three quarters of an hour, the day's residues are predominant. One is aware of the surroundings, recent problems, etc.

2. gradually, one begins to relax and enjoy the experience. The feeling of being isolated in space and having nothing to do is restful and relaxing at this stage.

3. Slowly, during the next hour, a tension develops which can be called a 'stimulus-action' hunger; hidden methods of self-stimulation develop: twitching muscles, slow swimming movements (which cause sensations as the water flows by the skin), stroking one finger with another, etc. If one can inhibit such maneuvers long enough, intense satisfaction is derived from later self-stimulations.

4. If inhibition wins out, the tension usually develops to the point of forcing the subject to leave the tank.

5. If these and other stages are passed without leaving the tank, one notices that one's thoughts have shifted from a directed type of thinking about problems to reveries and fantasies of a highly personal and emotionally charged nature.

6. If the tension and the fantasies are withstood, one may experience the furthest stage yet explored: projection of visual imagery. The black curtain in front of the eyes -- such as one 'sees' in a dark room with eyes closed -- gradually opens out into a three-dimensional, dark, empty space in front of the body. This phenomenon captures one's interest immediately, and one waits to find out what comes next. Gradually, forms of the type sometimes seen in hypnogogic states appear.

Modern anti-terrorist warfare has bared the subtle application of sensory deprivation in order to achieve military ends. As revealed by the European Human Rights Commission, these operations have consisted of five components: suspects were arrested at night, immediately isolated and hooded with black, insulated covers placed over their heads except during questioning; they were forced to stand at a wall in the search position, supported only on their fingertips and wearing loose-fitting boiler suits; they were subjected to a continuous, loud 'white' noise of 85-87 decibels. They were deprived of sleep for the first several days of a week of interrogation; and they were deprived of food except for a round of bread and a pint of water at six hour intervals. A large number of anxiety-producing results were suffered, such as hallucinations, confused thinking, nightmares and paranoid delusions. In this case, a rapid positive feedback spiral of increasing anxiety occurs which can only be ended with the volunteer giving up.

An individual experiment in long-term isolation and deprivation from the usual day-to-day sensory stimulation has been performed in a deep underground limestone cavern. The subject spent six months alone in the cave, under monotonous conditions of temperature and artificial lighting. The experience eventually contributed to a grave deterioration of his mental and manual dexterity. After three months, his hands, slow and clumsy, could no longer string beads and thoughts not scribbled down were quickly forgotten. His wake/sleep cycle sustained a 48 hour rhythm -- 14 hours asleep, 34 awake.

Although the conditions described above are far from those found in most living and working environments, the point is that there is a need for sensory stimulation from one's surrounding environment. The monotonous, 'flat' lighting and thermal regimes found in many of today's buildings could be counter-productive and a possible source of 'deprivation stress.' Linkage with the dynamic external climate can provide the variation in temperature, illumination and sound necessary for sensory stimulation, as long as it is held within limits which preclude distraction. The need to control light and heat assumes different values in each culture and the design of architectural countermeasures may be influenced accordingly. The provision of comfort in vernacular architecture creates the context for the architectural domination of climate achieved by the early modern architects of the 20th century.

The Science of Environmental Tempering Emerges

Fundamental to the development of a rational conception of an architecture which controlled light and air were the general developments in science during the 17th century. In 1664 the Royal Society consisted of eight permanent committees, three of the which -- Invention, Technical History and Georgics (agriculture) -- were directly concerned with 'the relief of man's estate.'

The basic science of mechanics was placed on a firm footing by Galileo and Kepler, who made the great break with the past. The study of acoustics was advanced by Kircher's illustrated treatise on the principles of acoustics, c. 1650, in which he describes the aeolian harp, a stringed instrument played by the wind, and the echoes occurring in 'phonic' rooms or whispering chambers, sometimes used as confessionals in which lepers could communicate privately with a priest over a considerable distance.

The Aristotelian theory of the four elements, earth, air, fire, and water was laid to rest by Robert Boyle(1627-91); he demonstrated that air is a substance which has weight and published his findings in The Sceptical Chymist in 1661. Mayow in 1668 demonstrated clearly that only a part of the air was necessary for life, and that this same part was removed both by respiration and by combustion. [Singer, 1962, p 163-165.]

Prominent among the visionaries of the time was Francis Bacon, whose chief scientific treatise is a clairvoyant account of future inventions: carts that would move rapidly without animals, flying machines and other unheard of engines. The coming mechanical apparatus had already been assembled in dreams. Bacon's list of discoveries and inventions in New Atlantis included the 'making of new species, retardation of age... and the creation of Chambers of Health where we qualifie the air' [a suggestion of air conditioning?] and means to convey sounds in trunks and pipes for long distances. Not the least of Bacon's anticipations was a skyscraper half a mile high, doubled in height 350 years later in the plans of Frank Lloyd Wright. The chief premise arising from the Baconian definition of technology and science is the nothion that there are no desirable limits to the increase of knowledge, material goods or environmental control.

With the passing of the Middle Ages, the design of buildings began to be characterised by a preoccupation with classical geometry. Open spaces appeared in towns, with their origins in Vitruvius' climatic prescriptions. Mumford describes the design of urban spaces dating from medieval times:

> Not merely were the streets narrow and often irregular, but sharp turns and closures were frequent. When the street was narrow and twisting, or when it came to a dead end, the plan broke the force of the wind and reduced the area of mud. Not by accident did the medieval townsman, seeking protection against winter wind, avoid creating such cruel wind-tunnels, as the broad, straight street. The very narrowness of medieval streets made the outdoor activities more comfortable in winter. But, likewise, in the south, the narrow street with broad overhangs protected the pedestrians against both rain and the sun's direct glare. [Mumford, 1966, p 354-55]

There seems to have occurred an internalisation of climatic thinking in both architecture and urban design during these times. Consideration for climate became a cultural ingredient of classical designs. Leone Battista Alberti for instance, linked the aesthetic allure of street patterns with its adaptation to environmental conditions. [Fitch, 1972, p 1-19.] Palladio in his book on the Five Orders had suggestions for cooling the hot Renaissance Italian villa by a system of flues conducted into an underground chamber from which cold air would circulate. Sebastiano Serlio in his treatise on architecture in 1537 illustrates chimneys and fireplaces. They are classical in inspiration, but Serlio was also concerned about their technical efficiency. The fire, he stated, should be lower than a man's face so that the flames which were believed to be harmful to the eyes, may warm the body without harming the sight.

The tempo of development of environmental technology thus gained momentum. Its architectural expression was influenced by the work of such people as Sir Henry Wotton (1568-1639) and Sir Christopher Wren (1632-1723), in particular by Wren's interests and abilities in science. Wotton's The Elements of Architecture, was published in 1624 at the height of freshened Elizabethan interest in architecture. Its relationship to the classical precepts of Vitruvius is clear; Vitruvius was well known in England, and there had been several writers on the subject; Andrew Boorde's The boke for to lerne a man to be wyse in buyldyng of his house (?1540) was one of the first examples. A more pretentious work was The first and Chief Grounds of Architecture (1563) by John Shute.

This was the middle of a transitional period; the age of Gothic had closed with the erection of King's College Chapel, Cambridge (1532). It was now largely in the great houses rather than ecclesiastical and secular public buildings that the Elizabethan ideals of architecture were expressed. In these buildings the control of the interior climate was the subject of renewed and careful attention.

One of the characteristic features of the great house was the large amount of wall space given over to windows, which drew Bacon's remark, 'You shall have sometimes fair houses so full of glass, that one cannot tell where to become to be out of sun or cold.' One of the writers of the time, Sir Balthazar Gerbier, in his Counsel and Advice to All Builders (1663), gave advice on avoiding excess in too bold a use of glass:

> Shun in the first place those spectacle-like cant windows [bay windows] which are of glass on all sides; for it may be supposed that the inhabitants of such houses and rooms with cant windows [exposed to the Northwest] may well imitate a merry Italian fisher, who [in a winter, windy, rainy day] had been stripped to his skin, and having nothing left to cover him save his bare net wherein he was wrapped [sitting on the highway] put his finger through one of the holes, asking to passengers what weather it was without doors.[Gerbier, 1663, p 12-13.]

Wotton makes reference to the provision of environmental comfort which reflects not only a knowledge of Vitruvius, who he called an extreme lover of luminous rooms, but of the climatic conditions which prevailed in Britain. He remarks on the climatic considerations and requirements for the proper siting of a building:

> . . . the quality and temper of the Aire: which being a perpetuall ambient, and ingredient, and the defects thereof, incorrigible in single Habitations . . . doth in those respects, require the more exquisite caution; That it be not too grosse, nor too penetrative; Not subject to any foggy noysomnesse, from Fenns or Marshes neere adjoyning . . . not undigested, for want of Sunne, Not unexercised, for want of Winde . . . .[Wotton, p 2-3.]

In defining the rules for the placement of rooms in relation to the climate, Wotton says:

> Let all the principall chambers of Delight, All studies and Libraries, be towards the East: For the Morning is a friend to the Muses. All Offices that require heat, as Kitchins, stillatories, stoves, roomes for Baking, Brewing, Washing, or the like, would be Meridionall. All that need a coole and fresh temper, as Cellers, Pantries, Butteries,

> Granaries, to the North. to the same side likewise . . . Galleries . . . that . . . require a steadie and unvariable light, which at any other quarter, where the course of the Sunne doth diversifie the Shadowes, would loose much of their grace.[Wotton, p 8.]

He also comments on the principles of orientation practiced by the Greeks and Romans,

> who did almost Religiously scituate the Front of their houses, towards the South; that being illustrated [illuminated] by the Sunne it might yield the more gracefull Aspect. [Wotton, p 9.]

He mentions the use of lighting for reasons of safety:

> the staircase should have a very liberall Light, against all Casualtie of Slippes, and Falles. [Wotton, p 57.]

Later he says that 'a Franke Light can misbecome noe AEdifice whatsoever', but cautions that a house should not be 'all Eyes, like Argus' which would be too cold in northern climates and in southern too hot. In support of Gerbier, he details the economic and material reasons for exercising caution in the use of glass:

> There is no part of Structure either more expencefull, than Windowes; or more ruinous . . . because consisting of so different and unsociable pieces, as Wood, Iron, Leade, and Glasse, and those small and weake, they are easily shaken. [Wotton, p 55-56.]

In addition to windows, elaborate chimneys were amongst some of the more ornate expressions of environmental control systems. Wotton spends a great deal of attention on the design of chimneys and the proper dimensions of the flue to avoid the inconvenience of smoke, making reference to the Roman hypocaust, which he called 'Caliducts.' He also refers to remarkably modern-sounding plumbing systems:

> [with] secret vents passing up through the Walles . . . to the wilde Aire aloft: which all Italian Artizans commend for the discharge of noysome vapours. [Wotton, p 64.]

William Harrison in his Description of England gave an idea of the visual impact of the proliferation of vents and chimneys which had begun in the middle 1500's. Old men in his village had seen great changes such as these in their lifetime:

> . . . [there was a] multitude of chimnies latelie erected, whereas in their yoong daies there were not above two or three, if so manie, in most uplandish townes of the realme -- the religious houses, and manour places of their lords alwaies excepted, and, peradventure some great personages -- but ech one made his fire against a reredosse in the hall, where he dined and dressed his meat. [Harrison, p 145.]

The reduced availability of sunlight in dense urban settlements led Wotton to propose changes in English building morphology which would make it more climatically responsive. He was aware that the ancients had used their courtyards as a means of admitting light and air to adjacent spaces;

> which we must now supplie either by some open Forme of the Fabrique, or among gracefull refuges, by Tarrasing any Storie, which is in danger of darkenesse; or lastly, by perpendicular lights, from the roofe: of all other the most naturall. [Wotton, p 69.]

And by way of commentary on social conditions in Britain, he modestly links good lighting with English hospitality:

> by the naturall Hospitalitie of England, the Buttrie must be more visible; and wee neede perchance for our Raunges, a more spacious and luminous Kitchin. [Wotton, p 71.]

On the display of artistic works in a gallery, he wisely described the ideal location of the work of art in relation to the light:

> that the best Pieces be placed not where there is the least, but where there are the fewest lights; therefore not onely Roomes windowed on both ends, which we call through-lighted; but with two or mo[r]e Windowes on the same side, are enemies to this Art; and sure it is, that no Painting can be seene in full Perfection but (as all Nature is illuminated) by a single Light. [Wotton, p 99.]

Thus he realised the necessity of 'focusing' the natural source of light, a technique often practiced by painters of the 17th century, as well as the advantage of a light source placed high in the room:

> Italian pieces will appeare best in a Roome where the Windowes are high; because they are commonly made to a descending Light, which of all other doth set off mens Faces in their truest Spirit [Wotton, p 99.]

Meteorology and Climate Control

In the early part of the 17th century, the understanding of light and vision was clarified by Rene Descartes (1596-1650), the French philosopher who gave a logical explanation of optical laws in his 'luminiferous ether' theory. Until then, the prevailing belief had still been based on the Greek -- and Hindu -- idea that vision is some sort of energy beam projected from the eye that 'feels' the objects in front of it. Descartes postulated that all space is filled with an infinitely elastic medium which transmits light as a kind of pressure in a similar fashion to the transmission of sound. It was not until two hundred years later that it was fully understood that light was a form of electromagnetic radiation, i.e., that it is energy radiated from an electron and this energy obeys to a limited extent the laws of wave motion.

Descartes and his followers developed a model which described the dualism of the body and the mind. This thinking was based on the idea that man consists of two separate entities, the body and the mind, which, though linked during life, are of profoundly different character. Descartes himself claimed that since the mind is a direct expression of God, its nature cannot be understood by science. [Descartes, 1641, p 22-36.] During the 19th and 20th centuries, the analogy between bodily function and machine elements made an impression on physiologists, who began to study man in terms of energy requirements, working efficiency and metabolism. It is interesting that Boileau made the accusation against Descartes that through his move away from mystical toward scientific meaning, he had 'cut the throat of poesy.' [Rykwert, 1980, p 161.] Both Newton's <u>Opticks</u> and Descartes' work helped revive the ancient notion of a concord of the senses. For instance, it was believed that the phenomena of colour, of colour harmony within the spectrum in particular, which were general and ascertainable, corresponded to numerical harmonic divisions, and these in turn to the notes of the tonic scale.

The Cartesian or Kantian version of the body / mind dualism represents the general paradigm of scientific investigation from the 17th century on. As Dubos pointed out,

> Since Descartes' time, the study of the body machine, its structure and its functions, has reflected directly the state of knowledge in physics, chemistry and other natural sciences. [Dubos, 1970, p 85.]

During the 17th century, the relationship of science to the art of building was reflected in the nature of the background and education of some of those who practised architecture. It was not until the time of Sir Christopher Wren that architecture was regarded as a profession. It had been an appropriate diversion for gentlemen and scholars like Wotton, Sir Francis Bacon, and John Evelyn, for whom it was 'the flower and crown as it were of all the sciences mathematical.' Wren himself was a mathematician, astronomer and experimental physiologist long before he became a practicing architect. The earliest English instrument for measuring rainfall was designed by Wren in 1662. [Symons, 1891 p 128.] It was designed so that its water container emptied when filled to a certain height. One year later, Wren designed the forerunner to the modern meteorograph -- a weather clock which was later perfected by Robert Hooke. [Middleton, 1969, p 248.].

Wren's weather clock consisted of two parts: a strong pendulum clock which, in addition to showing the time, turned a paper covered cylinder and operated a mechanism for making punches on the roll of paper once every fifteen minutes, and a set of instruments which measured pressure, temperature, humidity and rainfall. While somewhat impractically complicated, it illustrated great vision of the future of meteorological science.

The science of meteorology was becoming increasingly important in everyday life as well as in the design of buildings. Three of the most basic instruments in the development of an understanding of building climatology were first developed during this time; the thermometer, the barometer, and the hygrometer. [Crombie, 1953, p 346.]

Time and the weather information were publicly displayed. One monumental example of such an instrument was the air thermometer designed in 1662 by the physicist and mayor of Magdeburg, Otto von Guericke (1602-1686). It was constructed of copper and brass, nearly 20 feet high and fastened to the north wall of a building in that town. An angel, suspended by a chain and pointing to a scale on the tube, rose and fell in response to changes in temperature (Fig. 2.1). [Bolton, 1900, p 47.]

Sir Isaac Newton (1642-1727), pioneer in the application of steam power, was instrumental in establishing a thermometric scale. In 1701 he published a paper anonymously in the Philosophical Transactions, describing two reference points on the scale of his thermometer; the temperature of melting snow and of the human body, with the interval divided into twelve equal parts. [Newton, 1701 p 824-829.; Wolf, 1950, p 89.] Devices such as these symbolised man's increased understanding of -- and control over -- the climatic forces impinging on buildings.

In the 17th century, scientists influenced by Descartes began to accept the theory that water vapour was a distinct substance. Descartes held that all matter was composed of tiny, uniform particles distinguished from one another by their shape, which for water took the form of long, smooth, eel-shaped particles easily separated. [Descartes, 1668, p 227-230.] The measurement of humidity at this time was performed using readily available hygroscopic materials such as wool. One such rather clumsy device is described:

> If you suspend from one side of a large balance a large quantity of wool, and from the other side stones so that they weigh equally in dry air, then you will see that when the air inclines toward dampness, the weight of the wool increases, and when the air tends to dryness, it decreases. [Cajori, 1906, p. 48.]

This type of hygrometer was still in use until the early part of the 18th century. Other hygrometers were constructed over a two hundred year period, including those by Leonardo da Vinci and Robert Hooke, who used an instrument employing catgut, and later one using the 'beard of a wild oat.' [Middleton, 1969, p 86; Hooke, 1665, p 147.]

The standard method of obtaining humidity measurements today is by using wet and dry bulb thermometers. Although not perfected until the 19th century, they were first developed in the middle part of the

18th century by William Cullen, Professor of Medicine at Edinburgh, who confirmed that a wet thermometer was cooled through evaporation. [Middleton, 1969, p 122.]

Great changes in hygienic conditions and comfort came with the Industrial Revolution. It is often assumed that the physical evils of life became accentuated by the rise of the great towns. Nevertheless, investigation shows that the opposite was the case. During the 18th century men and women began to crowd into the great towns from the country. They were right in their choice, for their chances of life there were greater than upon the land. In the rural districts infamous housing conditions, an overcrowding beyond anything which we now have, exposure to weather, inaccessibility to medical aid, and the fact that in winter the roads were impassable, combined to render life, especially a child's life, more precarious than in urban areas.

The improvement of hygienic conditions in the towns began in England soon after the middle of the 18th century. Westminster obtained an Improvement Act in 1762, the city of London in 1766, Birmingham in 1765. As a result of such Acts noisome streams which had been open drains were covered over, the streets were paved and lighted, and the sewers were improved.

By the mid-19th century, the principles of fresh air, light and space were believed by some to be embodied in the human brain; Charles Fourier's disciple, Jean Baptiste Andre Godin (1817-1888) for instance drew on phrenology to justify his palatial factory settlement forms -- based on Versailles -- and a new 'science' of human relationships (Fig. 2.2). The four functions of the C.I.A.M. Charte _d'Athène_ of 1933 propounded a remarkably similar principle and we will return to this in the chapter on Le Corbusier. Godin's work pre-sages that of Le Corbusier in other ways: he started a foundry at Guise in 1846, employed 1,200 laborers, provided housing, cooperative shopping, schools, kindergarten, a theatre, baths, a park, vegetable plots -- a veritable Unite d'Habitation. Pensions and insurance were provided, and when Godin died, he left in his will the factory and 3,500,000 francs to the workers. [Pevsner, 1976, p 283.]

While the beginnings of rationalism are to be found in ancient Greek philosophy, it was Descartes' ideas which were translated into architectural terms by a number of theorists in the middle of the 18th century, including the French Abbe Laugier, whose Essai sur l'Architecture was published in 1753. Laugier tried to establish the fundamentals of architecture by thinking back -- by rational procedures. As a true rationalist, he was concerned with what the earliest buildings ought to have been, rather than what they actually were:

> Let us consider the man in his first origin, without any other help, without other guide than the natural instinct of his needs. He needs a dwelling place. He perceives, near a gentle stream, a green turf, the growing verdure of which pleases his eye.

This Eden-like environment also has the capacity for climatic hostility; first 'the sun's heat scorches him' and he looks for shelter in a nearby wood; but then 'a thousand vapours raised by chance' gather together and 'a frightful rain hurls itself down as a torrent upon this delightful forest'. He has to find shelter, and first tries a cave, but finds it too dark and 'unhealthful', so he sets about building a hut:

> He chooses four of the strongest [tree trunks] which he raises perpendicularly and disposes in a square. He lays four others across these, upon which he raises others sloping up from both sides. The roof thus formed is covered

> with leaves placed together so that neither the sun nor the rain can penetrate; man finally is lodged. [Sharp, 1978]

This could have only described vernacular shelter in tropical regions, for it was open on all sides and could hardly offer man protection from the environment at all.

On the eve of the Industrial Revolution, sophisticated environmental management techniques were beginning to appear in Europe. Paintings of the time tell us much about the quality of daylighting and the attention given to environmental comfort. During and after the 17th century the Dutch homeowner could exercise considerable control over the climate outside the window through a combination of openable sash, shutters located both on the exterior and interior and two sets of curtains, one for the control of light and privacy, the other for heat control (Fig. 2.3). [Rasmussen, Chapter 10]

One culturally-based spatial discovery whose development spans several hundred years was the inglenook, which reached a zenith in the work of Frank Lloyd Wright, and which will be analysed in more detail in that chapter. The formal evolution of the inglenook dates back to the 14th century, and is an example of the power of environmental control systems to change the shape of interior spaces. [Wood, 1981, p 234.] The inglenook became the very symbol of domesticity and as such was invariable in form:

> It was shaped like a small bay, the long side of which formed the hearth, while at either side were two little windows bringing direct light to the seats that flanked the hearth. [Muthesius, 1979, p 16.]

It was socially and functionally important that the seats have daylight to enable people to sit and read, converse or sew. Therefore, an outside wall was its most frequent location.

Environmental Tempering and the Window

The shape of buildings and the continuing movement towards an architecture of light and air depended on the development of the openings in walls. These openings -- later to become the window -- along with the evolution of the chimney to lead combustion gases out of living spaces, were both important steps in the evolution of environmental management systems. In huts of prehistoric times, slits in the walls measuring about 5 inches by 12 inches existed for admitting light and air. [Forbes, v 5, p 181.] The development of thermal, light and ventilation control for these openings in the walls probably proceeded along the following lines:

1. Shutters or mats were devised to cover openings in inclement weather.

2. Gratings of lattice or pottery to break the wind, rain and solar radiation (heat and light) were developed. These grilles, along with the small size of the openings in the walls also served for defensive purposes.

3. Early coverings for windows were varied: Eskimos used blocks of ice, ancients used polished marble slabs and also mica. Lapis specularis was used as late as the 9th c. in the church of S. Sabina on the Aventine.

4. Substitutes for glass, which could only be afforded by the rich, were devised of fish bladders, stomachs of cattle, horn, and parchment. the parchment was dipped in gum arabic, honey and white of egg, and stretched wet on a frame, varnished when dry. the specialists preparing such material were called 'sliemer' and were members of glaziers guilds.

As glass began to be used more widely for window panes, the use of a standardised terminology which indicated the function of this new material emerged in each culture: French verre, for glass in general but glace for window pane or mirror. Originally the Gothic augo-dauro -- eye door -- was used, which gave way to the Latin fenestra, from which subsequent derivatives came. Fourteenth century accounts use the word fenestrae to describe shutters and the translation of this word as 'window' is imprecise. French fenetre, Dutch venster, and German Fenster, were derived from the Latin. The Norwegian vindanga. and the Danish vidue are similar to the English 'window,' which is in turn derived from the word/concept 'wind-eye.' [Forbes, v 5, p 181, 183.] The French word, abat-jour, originally meant any beveled opening or sky-light in a wall or in a roof to admit light from above. If louvres (from the French l'ouvre) were placed in the opening, it became an abat-vent, which permitted light and air to enter but which deflected the wind and allowed smoke to leave. [Harris, 1977, p 2.] A related word, the abat-voix describes a development in acoustics -- the sound-enhancement reflector located behind and over a pulpit in churches.

By the middle of the 14th century the 'windowe' had entered literature and Chaucer, one of the perfect gentlemen of his time says in his Dreme, that in his bedroom,

> with glas were all the windowes
> wellyglazed.

They were well made and,

> Full clere, with nat
> an hole ycrased,

and moreover, so beautiful,

> That to behold it was great joy
> for holly all the
>
> story of Troy
> was in the glaising ywrought.

The windows were probably openable, for he says that when he was lying in bed, the

Windowes weren shut echone,
And Through the glass the sunne shone.
[Chaucer, 1602, folio 229.]

Devices such as frieze windows disturbed the external symmetry of an elevation; but perfection of the native English domestic style achieved balance and harmony without depending on symmetrical arrangement, as exemplified by such buildings as the George Inn at Glastonbury (1480) erected by Abbot John Selwood as a hostelry for pilgrims to the Abbey. The pre-eminently practical builders of inglenooks and oriels were guided by a typically English principle long before it was put into words by Francis Bacon, who said, 'Houses are built to live in and not to look on; therefore let use be preferred before uniformity, except where both may be had.' [Francis Bacon, Essays, 'On Building,' London 1561-1626.]

The draughts from unglazed windows were usually excluded by means of shutters which also eclipsed the light. In contrast to continental Europe, these shutters were usually hung on the inside walls in post-medieval England. In halls where windows occurred on both sides of the room the shutters were closed on the windward side, leaving the leeward side open to admit light and to permit smoke to escape from the central hearth. Various methods were relied on for the operation of the shutters. Some shutters opened by sliding -- horizontally or vertically -- or by hinges. In houses with large windows with transomes it was usual for the shutters to seal off the lower lights leaving the upper ones open at a height where the light would be advantageous and the draught would be least inconvenient.

The early double-sash window, probably introduced from Holland, was based on the proportion of the double square: each sash was vertically divided by three glazing bars and horizontally by two, framing twelve panes, an arrangement that persisted until the early years of the 18th century, when larger panes and fewer glazing bars were used in sashes. Where it was introduced, the proportions of rooms were usually improved and their comfort increased. In its Dutch origins, the head height of the double sash window reached to the ceiling and provided light which could penetrate deep into the room.

The sliding sash made as great a change in the character and proportion of houses as the use of the classic orders. They altered the whole aspect of a building because they brought the reflecting surface of the glass panes almost into the same plane as the walls surrounding the window. The result was that windows caught the sunlight, and the panes sparkled between their broad, white-painted wooden glazing bars; they were no longer set back into dark recesses formed by the thickness of the stone mullions that had framed the casements. [Gloag, 1956, p 28-31.] By the early 17th century, sash windows had appeared in England in such buildings as the Inigo Jones's Banqueting House at Whitehall (1619), with panes 13 inches by 10 inches, and glazing bars of wood, with continuous rectangular sinkings (called rebates or rabbets) cut along the edges to receive the panes, which were fixed with putty.

Politicians recognised a source of revenue in the abundance of windows; in their view, daylight was a luxury which could be forsworn if necessary. In 1697 a window tax was imposed that was not repealed until 1851 -- a symbolic date because it was the year of the Great Exhibition and the construction of the Crystal Palace. The tax was levied upon the number of windows: not upon any assessment of their area. Windows on ground-floor rooms became taller, rising from skirting level and terminating just below the cornice line; and if they rose from dado height they were still carried up as high as possible, so that the horizontal member of the window architrave adjoined the lowest member of the cornice.

Fortunately the window tax did not halt technical advances in glass manufacture. Windows had grown in size during the 14th and 15th centuries, not only in great churches and civic buildings but in town and country houses, and the making of glass had improved enough by the end of the 16th century that virtually transparent walls ascended in great bays from ground level to roof, rising through three or four storeys.

An early example of a window ascending through two storeys is in the house of Sir William Grevel at Chipping Campden in Gloucestershire. There were also horizontal extensions of glazed areas and in some of the large half-timbered English country houses of the late 15th century windows formed a transparent frieze above the interior panelling of halls and large living rooms, as at Ockwells Manor in Berkshire (c 1465) (Fig. 2.4).

The deliberate attempt to admit light as near the ceiling as possible in ground-floor rooms suggests that architects were anxious to make the most of available daylight; but they often defeated their object when they designed the interior decoration of those spacious rooms, for they restricted the admission of daylight with elaborate curtains, and stiff, heavy pelmets, which often concealed the upper part of the window, reducing its height, while the curtains narrowed its width.

The painted wood glazing bars that had enclosed the panes of the original sashes were flat and thick, becoming progressively thinner and more delicate in section during the 18th century; by the close of the Georgian period they were reduced to a knife-edge fineness and during the Victorian age disappeared altogether, as makers could then produce plate and sheet glass in bigger sizes so that the double-hung sash could have two large square expanses of glass instead of twelve small rectangular panes.

Clues to the construction of windows during this important period of their evolution is described in detail in paintings of the 15th through 17th centuries. One such painting is The Annunciation (c. 1425) by Robert Campin (Fig. 2.5). The window in the painting is typical of a wealthy house of the 15th century and shows two types of folding shutter and a fenestral. The small amount of glazing is confined to the two 'lights' above the texture.

The enlargement and increased significance of windows changed the character of domestic architecture drastically. In palaces and houses windows were no longer the small medieval apertures based on requirements for defense; they resumed their function as a way of connecting with the outer world, something well known in the Graeco-Roman civilisation but forgotten during the dark centuries. Windows now threw rooms open to gardens, parks and distant view, and in towns to the flowing colour and life of streets. Dutch houses of the 16th and 17th centuries represent the zenith of the delightful use of windows in high density row houses. The rediscovery that windows had a two-way function, to admit light to a room and to give visual pleasure, indicated that Europeans were acquiring a healthier and more reasonable idea of the art of living.

Daylight reflected from windows with glass panes arranged in a formal pattern gave glittering animation to a facade. Fenestration became an integral part of architectural design and a benign influence on the regulation of the appearance of the facade unknown in the ancient world, though anticipated by mediaeval builders who had progressively enlarged window space in churches and civic structures. Windows in English houses like Hardwick, dominated to such an extent that they justified the popular jingle: 'Hardwick Hall, more glass than wall'(Fig. 2.6) At the Chateau de Chambord, windows regulated the composition by unifying horizontal lines, partially resolving the conflict between late Gothic and the Renaissance innovations. [Gloag, 1977, p 217.]

Heating and Ventilation

The modish enthusiasm for classical forms and usages did not lead to the approval or adoption of the heating devices which had been perfected in Roman times -- Wotton's "Cali-Ducts," were never introduced. The Roman system of heating which was at the time the most efficient ever invented, was not revived; the architecture of Rome might have inspired and determined the proportions of English houses, but the hypocaust could not compete with the chimneypiece and the open fire-place. Architectural style seemed to be more important than environmental comfort. When heating systems were used at all, they were employed for conservatories.

Some of the ancient Roman prototypes found new forms, however in Central and Eastern Europe. Roman furnaces made up of wide-mouthed pots which formed the wall have been excavated in the remains of Nida. These seem to be the precursor of the later 'Kachelofen' found in

Hungary and Austria today. These ornate, airtight, slow-burning stoves, decorated with glazed tiles, became more prevalent as a means of heating the home in Central Europe, whilst the open fire grate remained more popular in the West.

By the end of the 16th century, the location of the fire had become a point of prime importance in determining the evolution of the plan of the house. In northern latitudes, the oldest arrangement had been a central fire kept in a hole in the ground with a hole in the roof -- protected by louvres -- directly above it to draw off the smoke. As the ashes were continually drawn away from underneath the fire, a pocket or basin was formed which held the fire itself. Thus the ebb and flow of life in these houses was always orientated centrifugally around the only source of heat and light. [Forbes, p 28.]

As the desire for a more controlled manner of drawing off the smoke grew, the fire probably was moved to the side or placed in the corner of the room so that the outlet for the smoke could be integrated with the structure of the wall. The shape of the hearth evolved in order to raise the fuel above the fire-bed and to promote combustion by inducing the draught underneath the fire. In primitive hearths, there were often three stones or bosses of mud placed in the fire between which the fuel was arranged and which served as a resting place for cooking vessels. Primitive tripods and andirons were the rude beginnings of the stove and of the conquest of the principle of induced draught.

The design of rooms and articles of English furniture was influenced by the habit of sitting round the fire. Wherever people sat in winter, there was usually a fire to comfort them. In the great houses servants lived and spent their leisure in the kitchen; in farm houses and cottages the kitchen was the living-room, cheerful, ample, and dependent for comfort upon the dimensions of the fireplace (Fig. 2.7). The fireplace in the farmhouse kitchen was almost an additional room, with its own furniture -- often built in -- including a warm though usually very hard seat in the chimney-corner, which was the early form of the inglenook (Fig. 2.8). Settles and benches and wainscot chairs were arranged around the fire. The function of the hearth as a symbol of domesticity and family can be seen clearly here. The phrase 'round the fire' and the 'fireside circle' dates back to the central open hearth of the great hall of the mediaeval house, and as fire-places built against a wall and directly connected with a chimney became common during the latter part of the 15th century, the circle changed to a semicircle; but it seems awkward to speak of sitting 'half round the fire,' or to refer to the 'fireside semicircle' or the 'fireside crescent'. Thus the form of social gatherings an the shape of the space are inextricably linked to the source of heat and light.

More significant to the shaping of larger buildings was the evolution of the closed stove into a form which permitted hot-air central heating. The earliest suggestion of this technique is in John Evelyn's Kalendarium Hortense, published in the middle of the 17th-century. [Evelyn, 1691.] His early furnace system for a hothouse had a combustion chamber which was raised above both the ash pit and induction air chamber by means of a grating (Fig. 2.9). An ingenious arrangement of the combustion air supply and the fresh air inlet insured positive ventilation and air circulation within the hothouse.

The combustion air ran through a pipe which was located under the floor. As air was drawn into the fire, fresh air entered the room through tubes which passed through the combustion chamber, thereby warming the air. A thermometer was located on the wall to assist the operator in maintaining constant temperature.

Evelyn also made recommendations on the general layout and orientation of an ideal hothouse, making provision for an air-lock system to minimise air leakage:

> That being placed at the most advantageous Exposure to the Sun; that Side be made to open with large, and ample Windows or Chasses, (for Light itself, next to Air, is of wonderful importance) the Joints, and Glazing accurately fitted and cemented: And (to the end that having occasion at any time to go into the House, no crude Air rush in)
>
> I add, that it were convenient, a Porch were so made, that the Door of it may shut very close after the Gard'ner, before he open the Green-house Door, which he is to shut again at his going out, before he open the door of the Porch at which he entred from abroad. [Evelyn, p 154.]

The tempering of interior environments before the industrial era reached its zenith in glass houses with the development of a series of sophisticated means of control. It wasn't until later that these methods were practised in offices and homes.

Summary

Cultural attitudes towards climate, hygiene and human comfort are important in shaping the architectural response to environmental forces. The need to control light and heat assumes different values in each culture and the design of architectural countermeasures may be influenced accordingly. Attitudes toward comfort in historical times and in primitive societies inform us when compared to the level of environmental tempering required by modern societies and delivered by today's architect. In addition, vernacular approaches to the provision of comfort provide prototypes for the architectural domination of climate which was achieved by the early modern architects of the 20th century.

Scientific understanding of environmental forces during the 17th century accompanied the development of systems for controlling heat, light and air in buildings. Environmental technology affected architectural expression in small ways at first: The scale of building types was sufficiently small that methods for controlling the environment could operate with a minimum of moving parts. The size of windows increased, improvements to heating systems were devised and daylighting from high windows permitted the design of new building types. The development is circular: Increased urban densities created a demand for new methods of delivering heat, light and air to interior spaces. At the same time, discoveries in the use of external operating energy made possible the mechanical systems which permitted buildings to grow in size and functional complexity.

3. The Environmental Challenge of Large Buildings

The 18th century began an important period in the development of modern functionalism in environmental control systems. Nevertheless architects showed little interest in such technicalities; no courses in heating or ventilation were given at the Ecole des Beaux-Arts, and Leonce Reynaud at the Ecole Polytechnique, suggested that the subject was of more concern to specialist craftsmen -- or fumistes, as they were called -- than to architects. [Collins, 1965, p 236.] Thus the technology of environmental control was considered to be beneath the dignity of the architect, however the necessity of providing visual and thermal comfort found expression in the larger buildings with techniques borrowed from other building types.

For instance, the heating of a number of rooms and floors from a single source developed in the 18th century from the use in France of hot-water heating for horticultural purposes. Another 18th century invention in mechanical services which affected the planning of buildings was the cast iron stove, which had been invented in Russia and which was first introduced into western Europe in 1767. In itself, it does not seem to represent a very radical departure from the systems of heating used before 1750 -- little better than open fires. In fact these stoves were revolutionary in that they reinstated the principle of heating by means of radiation or convection from hot metal surfaces, begun by the Romans with their hypocaust heating for villas and baths. [Collins, 1965, p 236]

Radiant heating was introduced in large buildings such as the Bank of England, where the smoke from the stoves was ingeniously sucked downwards under the floor, eliminating the intrusion of flues and chimneys where they were not wanted. However, the stoves had to be removed in 1787 because the employees protested that the warmth emitted from the surface of the cast iron was unwholesome. The air in the room was not changed and purified as it would be by a common fire, and the employees claimed that the stoves produced disorders of the lungs, and that they were afflicted with a new disease described as 'the iron cough.'[Collins, p 236.] The system was replaced in 1792 by the first commercial installation of a hot-water heating system using large bore pipes and a simple boiler. [Guedes, 1979, p 201.] By the 1840s, both low pressure and high pressure hot water systems were widely popular, especially after cast iron radiators were substituted for coils of pipe (Fig. 3.1).

The use of a gravitational system for circulating heat was also introduced around this time, the origins of which can be traced to at least 1777, when an inventor named Bonnemain used it as part of a patent incubator he had devised for hatching eggs. As early as 1784 James Watt (1756-1819) used a steam heating system for the cotton factory he had designed for a Mr. Lee of Manchester, where the steam was circulated through the hollow iron columns used to support the floors -- a perfect example of integration of environmental control with structure in a building. [Collins, p 236.] Successful spinning of cotton also depended on careful control of humidity -- the threads have a tendency to break if the air is either too humid or too dry. This led to the development of the humidifier, which introduced atomised water droplets into the air. The atmosphere of the factory was kept within a narrow range of environmental limits, but not for the workers' sake.

The need to ventilate large public buildings, such as hospitals, prisons, theatres and other places of assembly had a profound effect on planning. The first serious attention given to this matter in a monumental building occurred during the design of the new Palace of Westminster. In 1723, Dr. Desaguliers had tried to improve the primitive system introduced by Sir Christopher Wren in the original 17th century edifice by installing a centrifugal, hand-operated fan. The man whose job it was to turn the fan became known as the 'ventilator.' However, the ventilator occupied a space which the custodian considered to be his own, and he sabotaged the system. As late as 1791, the House of Commons was heated by open charcoal braziers which rendered the air 'pernicious in the extreme.' [Forbes, p 35.] From such a sorry state of affairs, the House of Commons later became a prototype which showed the power of ventilation technology to generate architectural form.

The original building was destroyed by fire and much attention was given the design and planning of the system for the new building. A digest of the building research and knowledge in heating and ventilating technology accumulated to that time is contained in the report of the building committee. [<u>Report of the Committee of the House of Commons on Ventilation, Warming and the Transmission of Sound</u>, 1836.] In this report, evidence is presented by a number of architects and scientists, including Michael Faraday, but only one man had any positive and constructive proposals to make on the subject, David Boswell Reid. Reid, a Scottish physician, made ingenious suggestions, such as that the air should be drawn over bags of ice in summer so as to keep the building cool. He also recommended a large air chamber or reservoir provided with purifying washers and heaters. The final solution incorporated 'thermo-ventilation' -- air propelled by convection heat from a furnace instead of by fans. Efficient fans for the movement of ventilation air had to await the invention of the electric dynamo.

The necessity for the provision of large ducts and tall chimneys led to a quarrel between Reid and Charles Barry as to the amount of such space to be allotted. Barry claimed that if Reid had his way, the greater part of the building would consist of nothing but ventilation ducts, whereas Reid, like so many later enthusiasts in this field, considered the perfection of his own speciality to be the only thing that mattered. The quarrel is interesting as it marks the first occasion in the modern era when mechanical services had a real influence on the architectural design of a large building (Fig. 3.2). [Collins, p 236.]

By 1850, the impact of the technology of the industrial era was pervasive in everyday life. With the advent of the steam engine and factory-produced glass and steel, time and space were annihilated. Building services reached a high level of sophistication and were made widely available to the urban dweller. The stage was set for the entry of a 'modern' thermally- and visually- comfortable dwelling and working space. The relation between man and nature was being transformed. On every side, there was a human display of titanic powers. The sight of the new technology provoked one writer to ask,

> What is there yet to be done upon the face of the earth, that cannot be effected by the powers of the human mind?

The answer is given that man '. . . is indeed, the lord of creation,' and all nature, as though daily more conscious of the conquest, was progressively offering less and less resistance to his domination. Hyperbolic literary praise of technology and progress helped to elevate the nineteenth century engineer/inventor to hero status. [Marx, 1964.]

At least four major types of building provide particularly good historical illustrations of the growth of functionalist idealism after the Industrial Revolution and its influence on modern architecture; namely factories, prisons, theatres and hospitals. All were essentially creations of the early Industrial era beginning in the mid-18th century, and all possessed the common quality of demanding that certain clearly defined environmental functions be fulfilled by the architectural form.

In factories there was a demand for lighting to extend the working hours through the night in northern latitudes, and a need for constant temperature and humidity for some manufacturing processes. In the new prisons there was a demand of course for maximum supervision, with a secondary but important requirement for environmental services. The new hospitals imposed an overriding demand for maximum ventilation, temperature control, daylighting and other services; the new theatres required good visibility, ventilation and acoustic control. All except the prison demanded easy egress in case of fire. It was in buildings such as these that modern environmental functionalism best expressed itself, and as a result, there was a considerable amount of architectural research on these building types in the nineteenth century.

Prisons and theatres were the first buildings to be dealt with in monographs on building types whilst hospitals constituted the first type of building to be the subject of serious scientific research. An Architectonography of Prisons, or Parallel of the Different Systems of Planning of which Prisons are Susceptible was published by Louis-Pierre Baltard in 1829. It was perhaps inspired by John Howard's State of Prisons, published in 1777. Pierre Patte published his Essay on Theatre Architecture in 1782. The French Academy of Science published its lengthy report on Poyet's project for a new city hospital -- Hotel Dieu -- in Paris in 1785. All three works are of interest because they show the part played by architects in initiating improvements, or, more frequently, in putting into tangible form the improvements in ventilation, heating and lighting envisaged by laymen. They also demonstrate the importance played by the Classical notion of standardisation -- a notion which was paradoxically rejected by those architects who have sought to create dramatically original works of art -- which implies that once a perfect architectural solution has been found, it is worthwhile to repeat its elements with minor variations and improvements in every situation where it is required.

Pierre Patte unabashedly proposed in his Essay on Theatre Architecture that standardisation might reduce all designs for theatres to just one type:

> It may be objected that theatres will henceforth have only one form, and that it will then be necessary, as in Antiquity, for all theatres to look alike; but why not? Will it in fact be so great an evil to reduce all such structures to the character proper to their destination, which consists in seeing well and and hearing well?

Patte was a Classical architect of the old school, so that for him, standardisation was not distasteful. He may also be regarded as a Rationalist in that he published studies on fireproof construction and urban design, and wrote the two volumes on building construction which posthumously completed J.F. Blondel's published lecture course.

Sir Samuel Bentham's 'panopticon' system, often attributed to his brother, Jeremy, was originally invented for supervising factory workers, but adapted to prison cell planning, whereby blocks of cells radiated from a central inspection post, much as the stacks radiate along lines from the staff desk in Stirling's Cambridge History Faculty building. [Pevsner, 1976, p 163.] Baltard perceived the basic analogical fallacy upon which it, like so many other misleading aspects of the new theory of Functionalism, was based:

> The English bring into all their works the genius for mechanics which they have perfected, and they thus want their buildings to function like a machine worked by a single motor. [Collins, 1965 p 232 f.]

This is the beginning of the functional theory of the machine age, for this phrase could hardly have expressed more clearly the idea of a prison as a 'machine for living in,' or a factory as a 'machine for working in' (Fig. 3.3, 3.4, 3.5).

Prison design influenced hospital design when in Poyet's project for rebuilding the Paris Hospital, Hotel Dieu, he proposed the panopticon principle in order to facilitate communications rather than for centralised supervision. His scheme was rejected by the French Academy of Science, based on their knowledge of the Hotel Dieu at Lyons, where the centralised arrangement of spaces enabled the altar to seen by all the patients. The Academy objected to the panopticon principle on the grounds that it prevented good ventilation. The new principles of planning led to a system of isolated pavilions to both allow better ventilation and at the same time check the spread of contagion.

Until that time there had been little understanding of the therapeutic value of ventilation and it was considered quite ordinary for six persons to occupy one hospital bed, or for 110 beds to occupy a room eight metres square in the old Hotel Dieu in Paris. The development of artificial ventilation at this time was largely due to research on hospital and prison design. In 1753 Dr Stephen Hales had introduced mechanical ventilation into Sir John Oldcastle's smallpox hospital, as well as into the Winchester, Durham, Shrewsbury, Northampton, Newgate and Maidstone county jails (Fig. 3.6). In about 1830, an engineer named Charles Sylvester introduced an ingenious system of ventilation into the Derby Infirmary, whereby fresh air was brought in by means of an underground tunnel, 200 metres in length, along which it was heated in winter by means of a large stove.

The first institution for open-air treatment of pulmonary tuberculosis was that established by George Bodington(1799-1882) at Sutton Coldfield. [Singer and Underwood, p 228.] A sanatorium for treatment on open-air lines was opened in 1859 by Hermann Brehmer (1826-1889) at Goerbersdorf in Silesia. The environmentally determined shape of patient wards of the mid-19th century is shown clearly in the layout of the New York Hospital (Fig. 3.7). The sanatorium as a building type can be traced for nearly a century right through to Aalto's Paimio Sanatorium and was based upon open-air treatment, the principle of subjecting the patient to absolute rest until his fever has subsided, and then to exercising the body very gradually until he can go through a day involving light work without adverse reaction.

The cotton mill was again the setting for the introduction of new technology with the first large scale installation of artificial lighting in 1806 near Manchester, when over 900 gas-lights to illuminate the factory and a private residence were installed by the firm of Boulton and Watt. The burning of gas for light remained unpleasant, however and the opinion of the user is best indicated by the prevalence of special ventilating pipes called perdifumes, placed over the gas burners. The truth was that neither the quality of the gas itself, nor the technical skill with which installations were made could protect the consumer against serious discomfort in small rooms. In 1833 it was suggested in the Mechanics' Magazine that the best way to light a room by gas was to place the burner outside the window! The atmospheric burner, which brought air into the gas stream immediately below the burning-point gave much more complete combustion, which, along with the incandescent gas mantle, gave gas new life as an illuminant until the end of the century. [Derry and Williams, p 512.]

In its early years, it was claimed that gaslight adequately replaced sunlight, so that the moral question of forcing children to work a twelve-hour day in factories was blunted. To its credit, however, gas-light played an enormous part in the development of the habit of reading among a population that became increasingly literate after the Elementary Education Act of 1870. The later development of the factory as an environmentally tuned machine can be seen in the work of Albert Kahn in and around Detroit, Michigan in his design of buildings for the manufacture of automobiles (Fig. 3.8).

While not as widespread as the other large building types, the art gallery also presented an environmental challenge to the architect, especially in lighting. The early galleries were for the first serious art collectors of the Italian renaissance. These collections were privately owned and displayed in the houses and palaces of the wealthy. By the early part of the 17th century, the inclusion of an art gallery was a standard element of palace planning. The first purpose-built art galleries, as special rooms or passages in large homes, occurred in the mid 16th century.[Pevsner, 1976, p 112.] These galleries were built with tall vertical windows which in some cases were supplemented with roof lights. One of the earliest public galleries in England was the British Museum. Roof lighting became the main source of light since all available space was needed to hang the collection.

One of the first examples of the use of sky-lighting in France was in the Louvre in Paris. In 1784, M. Reynard proposed that the vertical windows should be replaced by a roof lighting system. The earliest form of roof lighting consisted of simple horizontal glazed panels positioned over the center of the space which directed most of the light onto the central region of the floor. Because of this form of design, the person looking at the paintings was generally standing in a relatively high level of light and this produced distracting reflections on the surface of the painting. Although a high level of light fell on the paintings, they were not the brightest areas of the gallery and hence had a tendency to appear dull by comparison.

Over the years the top-lighting schemes developed in a number of ways in an attempt to provide a predominance of light onto the display surfaces without the complication of unwanted reflections. Examples of these are the lantern lights used in the Sir John Soane's Dulwich Gallery, which was the first independently owned gallery in England to be opened to the public.

The height of buildings determined to some extent the penetration of daylight to the street below and this became the subject of the London Building Act of 1894. The height of the building was regulated by an imaginary straight line from the rear boundary of the site sloping towards the house. Legislation determined building form, as no part of the building could project beyond that line. The draft bill suggested 45 degrees for the slope of the line, but, according to Muthesius, the large landowners sitting in Parliament forced through the amendment that nullified the intent of the law. Therefore, the angle came to be 63 1/2 degrees (Fig. 3.9). [Muthesius, p 75.]

In cities, the small light-well replaced the inner courtyard to allow access to light and air. The light-well was common in multi-storeyed apartments at the turn of the century. The minimum dimensions were set by the distance between the opposite wall and a window, which was at least half the height of the light-shaft, measured from the sill of the window.

The growing number of larger public buildings created a challenge for architects to substitute ideal arrangements for what had previously been <u>ad hoc</u> adaptations of existing buildings. Just as the earliest hospitals had usually been modified dwellings or monasteries, and the earliest prisons modified fortresses, so the earliest French theatres were often modified tennis courts, and no adequate provision was made for proper acoustics, proper ventilation, lighting, sight lines or proper protection against the hazards of fire. The discoveries and developments in the technology of environmental tempering which were made around the end of the 19th century made it possible to overcome the difficulties in designing for climate in buildings of monumental scale and paved the way for Wright, Aalto, and Le Corbusier.

Summary

As buildings grew in complexity, so did the requirements for and the methods of controlling the environment within. Slowly, almost begrudgingly, new architectural forms were created to bring in light and conduct air; the first examples of skylighting and early types of air-conditioning appeared. Technology gave the means for achieving control, but architecture was not quick to welcome the new techniques. New industrial building types appeared and were made habitable by ducted heating and cooling systems and artificial lighting. Mills and factories inspired schemes for environmental tempering in the name of increased productivity. The specifically new types of buildings, the hospitals, prisons and theatres, were the locus of architectural integration. All these types required control of heating, ventilation and lighting and as new environmental systems were developed for new building types, the 'fumistes' became the keepers of environmental knowledge. 'Architecture' was taught elsewhere, at the Beaux Arts. These events led up to the techniques of environmental tempering and the architectural shapes which were developed in the 20th century.

4. Environmental Tempering and the Two Cultures

> Science and engineering produce 'know-how'; but 'know-how' is nothing by itself; it is a means without an end, a mere potentiality, an unfinished sentence. 'Know-how' is no more a culture than a piano is music.
> -- E. F. Schumacher

Is the design of the well-tempered environment more than the application of know-how? An answer may be found by looking at the history of architecture in the context of the Two Cultures -- the very different worlds of Art and Science which have been accommodated in architectural design since classical times. To satisfy the demands of both worlds, designers have had to balance seemingly contradictory technical and artistic requirements. They find that one world limits the other. To have shelter, there must be a span -- strength of materials can therefore be said to limit creativity. The modulation of light, air and temperature requires an opening in the structure and the use of glazing -- structural limitations and the characteristics of glass therefore constrain the extent of artistic expression.

Failure to resolve the science and the art of design leads to an architecture which is 'out of tune' with the climate and with cultural expectations for its performance. On the other hand, successful examples of the architecture of the well-tempered environment are invariably the result of the synthesis of art and science. The successful fusion of the Two Cultures in design results in an architecture which delights, but a conflict between them is often resolved at the expense of human comfort. A failure in either the art or the science of environmental tempering invariably results in mediocre spatial qualities or worse.

C. P. Snow, who called science and the arts the 'Two Cultures,' believed that 'the intellectual life of the whole of western society is increasingly being split into two polar groups.'[Snow, 1959, p 4.] But he optimistically predicted that

> The clashing point of two subjects, two disciplines, two cultures -- of two galaxies, so far as that goes -- ought to produce creative chances. In the history of mental activity that has been where some of the break-throughs came.

Of course there are many permutations in the definition of the two cultures. B. P. Medawar holds that the scientist cannot be easily classified; there is no such thing as a Scientific Mind:

> Scientists are people of very dissimilar temperaments doing different things in very different ways. Among scientists are collectors, classifiers and compulsive tidiers-up; many are detectives by temperament and many are explorers; some are artists and others artisans. There are poet-scientists and philosopher scientists and even a few mystics. What sort of mind or temperament can all these people be supposed to have in common?

On the other hand, there is the view of Shelley, who claimed in his Defence of Poetry that science and poetry are antithetical:

> [For poetry] is not like reasoning, a power to be exerted according to the determination of the will. A man cannot say 'I will compose poetry.' The greatest poet even cannot say it . . . . Poetry . . . is not subject to the control of the active powers of the mind, and its birth and recurrence have no necessary connection with the consciousness or will.

Poetry was a metaphor often invoked by Wright, Le Corbusier and Kahn; Frank Lloyd Wright likened the architect to a poet when he said:

> Every great architect is -- necessarily -- a great poet. He must be a great original interpreter of his time, his day, his age. [Wright, 1953, p 232.]

Louis I. Kahn in his inimitable style asks a rhetorical question about the difference between a poet and a scientist:

> Where is the scientist and where is the poet? The poet is one who starts from the seat of the unmeasurable and travels towards the measurable, but who keeps the force of the unmeasurable within him at all times ... The scientist ... holds his line and does not travel with the unmeasurable because he is interested in knowing. He is interested in the laws of nature, so he allows nature to come to him . . . He receives knowledge in full and works with this, and you call him objective.

Kahn goes on to describe Einstein, the quintessential scientist who in modern times had transcended the meaning of the word:

> Einstein travels like a poet . . . . He also reaches nature or Light at its very doorstep . . . . He deals with Order and not with knowing . . . . Thus, he could lead you to a sense of all of Order, which knowledge is really answerable to . . . . There is nothing about man that is really measurable. He is completely unmeasurable. He is the seat of the unmeasurable, and he employs the measurable to make it possible for him to express something. [Lobell, 1979, p 14.]

The spirit of architecture seems antithetical to that of engineering, the two coming together only imperfectly. Intuition, magic, eccentricity, unfulfilled yearnings -- architecture is a mirror of the imperfections of human life. The two worlds are antithetical, but they desperately need each other. This was expressed by no less an authority on the matter than the late Mies van der Rohe, when interviewed by Philip Johnson:

> Technology is rooted in the past. It dominates the present and tends into the future . . . . As a method it is superior in almost every respect. But only where it is left to itself, as in gigantic structures of engineering, there technology reveals its true nature. There it is evident that it is not only a useful means, but that it is something, something in itself, something that has a meaning and a powerful form -- so powerful in fact, that it is not easy to name it.
>
> Is that still technology or is it architecture?
>
> And that may be the reason why some people are convinced that architecture will be outmoded and replaced by technology. Such a conviction is not based on clear thinking. The opposite happens. Wherever technology reaches its real fulfilment, it transcends into

architecture . . . . That is the reason why technology and architecture are so closely related. Our real hope is that they will grow together, that some day the one will be the expression of the other. Only then will we have an architecture worthy of its name: architecture as a true symbol of our time.[Johnson, 1954, p 203.]

It is clear that the technology of environmental control in Roman architecture was more than science. The perforated domes of the baths, which made possible a new architecture of space and light, required more than the discovery of concrete with its new structural possibilities. For their creation, they depended not only upon a comprehensive poetic interpretation of the application of new materials and systems, i.e., concrete, ducted heating systems and glass, but also a sophisticated knowledge of climate and comfort which then allowed the arrangement of spaces in a particular, thermally graded sequence and in proper orientation to sun and wind. In a simple, integrated and dramatic way the program for a public bathing facility was met.

The influence of Roman architecture continues to be felt by succeeding generations of architects. In quattrocento Italy, Imperial Rome embodied the Golden Age, '. . . a time when man led an idle, amiable, carefree existence, without passion, without curiosity.'

The importance of this myth cannot be underestimated; it signifies our difficulty in forming a vision of the future without reference to the past. For a thousand years the remains of Rome had raised only dim emotions and had been objects sometimes of aversion and fear. Then, ancient Rome began to arouse in some architects a deep fascination -- even an obscure veneration. The intellectual gulf between Two Cultures is first described in the early writings of Alberti and Colonna. The difference between Alberti and Colonna was this: Alberti rationalized the notion of antiquity as it had taken shape in his mind, overhauling the entire structure, nearly to its foundations; Colonna on the other hand approached his classical world obliquely. For him the picture was almost too delicate to touch. There is a resonance between Hypnerotomachia and later romantic works such as William Morris's New from Nowhere.

Summerson concluded that Alberti and Colonna were two wholly different types of person, reflecting the difference between the Two Cultures, or during the Renaissance, the difference between Florence and Venice:

> Alberti was one of those tough, energetic thinkers to whom intuitive capacity is somewhat limited. Colonna, on the other hand, was not a thinker; feeling and intuition dictate his attitudes all the time. He would be incapable of putting on a performance like De Re Aedificatoria, and Alberti would find Colonna's record of subjective experience incomprehensible and childish. [Summerson, p 145.]

Developments in technology during the Renaissance also changed the perception of man's relationship to nature. With the invention of the geared clock with pendulum, pulleys and weights towards the end of the 13th century, a distinction between Technology and Nature was made. The clock introduced hours of equal length, whereas previously day and night had been regarded as independent units, each divided into twelve hours. As a result, hours had been of different length according to the season. In summer there were long day-hours and short night-hours, and in winter the reverse. The length of the hour now became independent of changing seasons, signifying a very distinct withdrawal from Nature. Technology, or the mechanism of the clock, had ousted Nature.

The injection of science into architecture at the eve of the Modern Movement began with Cesar Daly's attempts to 'modify the effect by modifying the cause' in 1840. This evolved into what was later called 'functional' domestic architecture in the 1920s. Even though the scientific tradition in architectural design was well established by the 20th century, Le Corbusier, Wright and Aalto often designed independently -- or in contravention -- of the recommendations of engineers or scientists and scientifically conducted research. The failures have not gone unnoticed, but in most cases the various types of human environment have profited from the architects' initiative.

To what extent this process is tellological -- i.e., that the new technologies for lighting, heating and ventilation were developed primarily for the purpose of creating well-tempered spaces -- is difficult to answer. More likely, it has been a case of the visionary use of borrowed technology and metaphors -- new uses and arrangements for old techniques -- which have made the achievement of the well-tempered environment possible. For example, Joseph Paxton used glazing systems already known and previously developed, albeit at a never-before-attempted scale and with new vision, to achieve remarkable effects in environmental tempering.

Both Le Corbusier and later Buckminster Fuller felt that the new technology of the 20th century, which brought with it the power and potential of the machine, would also bring with it a period of Utopia. That it did not do so is a matter of history. Not since Pericles, the Purists argued, had thought been so lucid; they believed that the modern age would realize the true aims and ambitions of the Greeks. How did the Purists aim to carry out this ambitious program? Ozenfant and Jeanneret thought it would come through 'mechanical order'. 'Man', they wrote, 'is a geometric animal, animated by the geometrical spirit'. This emphasis was to be found at the root of the numerous arguments in Vers une Architecture.

Le Corbusier called for a modern architecture in response to the challenges posed by the industrial exigencies of the present and the architectural lessons of the past. 'Past' architecture for him consisted mostly of Greek and Roman examples:

> Roman. The word has a meaning. Unity of operation, clear aim in view, classification of the various parts . . . The light plays on pure forms . . . . Simple masses develop immense surfaces . . . . The Pantheon, the Colosseum . . . the Baths of Caracalla. [LeCorbusier, 1927, p 146.]

He found in Roman architecture a partial answer to his own early quest for a formal balance between the contradictory requirements of use and design -- science and art. There is a dichotomy in Le Corbusier's definition: architecture is a product of a synthesis of science and art -- of reason and emotions. When Le Corbusier wrote his l'Esprit Nouveau articles he was still thinking largely in terms of the individual designer, as one isolated from a collective responsibility in the modern technological world. After CIAM in 1928, designers and architects shifted their attention to working class housing, expressed in technical, social and economic terms. Scientific needs were defined, perhaps too simply as 'light, air and space'.

As evolving technology has conquered functional limitations, new possibilities in shaping the well-tempered environment have arisen. Frank Lloyd Wright acknowledged the ancient origins of his ideas for placing home heating systems in the floor, but his application of the principle was a fresh, new approach. He interpreted the application of Roman technology to his own purpose in 1938 when he described the environmental control systems in his Usonian houses:

> . . . a steam warmed concrete mat four inches thick . . . no radiators and no light fixtures. We will heat the house the Roman way, that is to say, in or beneath the floors, and make the wiring system itself be the light fixtures, throwing light upon the ceiling. Light will thus be indirect except for a few outlets for floor lamps.

Among the philosophers of science, Stephen Toulmin and Michael Polanyi are two who give encouragement to those who want to make a place for science in the humanities. The latter's recondite, Personal Knowledge, is a philosophical attack on the objectivist theory of scientific knowledge. [Polanyi, p 109.] Polanyi attacks the fallacy which makes science the ideal form of all knowledge in the West, and the demands placed on science for perfect objectivity.

Theories of classical physics, says Polanyi, can be verified or falsified by an appeal to empirical evidence, but very little else can, even in the sciences. Empirical evidence alone has never constituted scientific proof; the beliefs in astrology and witchcraft had a great deal of evidence to support them; far more than there could be against them.

The objectivist view requires that we think of science as the most economical description of a set of facts, or as a set of working hypotheses, or as just a policy for drawing empirical inferences. Science is more useful to the architect if it is thought of as the discovery of a hidden reality. Simplicity, symmetry, economy, are the marks of rationality, not the marks of truth as a whole, even scientific truth. Scientific theories cannot then be accepted without acknowledging also their beauty and their profundity, two other categories of reality, and not objectively knowable.

If we accept Polanyi's logic, then there are three reasons why scientific knowledge is necessary for the fusion of architectural form and technological function: First, science is the power and the magic of today; the arts are the sense of inspiration and prophecy. An imaginative designer needs both, needs to participate in contemporary science in the sense in which a reader participates in contemporary literature.

Secondly, it is necessary because science is a body of vital information as well as a discipline. We cannot respond in any vigorous way to the new, man-made things, the great machines, the latest advances, all of which have become the texture and substance of modern life, unless we know enough about it to accept it emotionally as the creation of our own culture.

Thirdly, it is necessary because at the heart of all science is the impersonal, objectivist mode of knowledge, which is the natural complement to the artistic and lyrical mode of understanding. The subtle penetration of even the most intimately personal design by an impersonal mode of feeling can result in the power of generalization to the common experience.

Hugo Haering, in his "House as an Organic Structure", written in the 1930's, summarizes the theme of this chapter:

> 'There remains an essential difference between the architect and the engineer. The work of the engineer has as its goal merely the performance of material work within the limits or in the domain of economic effects. That the result frequently contains other expressive values as well is a side-effect, a subsidiary phenomenon of his work. The architect, on the other hand, creates a Gestalt, a total form, a work of spiritual vitality and fulfillment, an object that belongs to and serves an idea, a higher culture.'
>
> 'This work begins where the engineer, the technologist, leaves off; it begins when the work is given life. Life is not given to the work by fashioning the object, the building, according to a viewpoint alien to it, but by awakening, fostering, and cultivating the essential form

enclosed within it.'

To what extent this process is teliological -- i.e., that the new technologies for lighting, heating and ventilation were developed primarily for the purpose of creating well-tempered spaces -- is difficult to answer. More likely, it has been a case of the visionary use of borrowed technology and metaphors -- new uses and arrangements for old techniques -- which have made the achievement of the well-tempered environment possible. For example, Joseph Paxton used glazing systems already known and previously developed, albeit at a never-before-attempted scale and with new vision, to achieve remarkable effects in environmental tempering.

Beyond the physical constraints and conflicts in the application of technology as a means to achieve artistic ends, the Two Cultures represent two different, oftentimes polar-opposite ways of thinking about environmental problems and their solution. The adherents in the arts and architecture vibrate to quite different modes of thought than engineers and those in the sciences, having to do perhaps with the differences between the workings of numbers and the workings of design and composition.

In the physical sciences and engineering, laws hold sway. That to every action there should be an equal and opposite, or contrary, reaction is absolutely confirmable. One can count on it. In engineering design one moves step by step, with full trust in the outcome, toward something that has forever been there waiting to be shown. There is a great beauty in the proofs of such structures. The engineering mind habitually copes with formidable tests of rigour and discipline. Exact answers give much comfort, regardless of the meaning which comes from such precision. Numbers, aside from their love of hide and seek, are docile. The obedience of numbers can make engineers overoptimistic.

By comparison, the intuitive aspects of architectural design are a tangled growth of honeysuckle gone wild. The non-technical part of architectural design is lawless; there are only conventions and styles, whose greatest beauty lies in their delicate mutability. Here we can count on nothing. Nothing can be proved. If you attempt to offer proof of Wright's Fallingwater or LeCorbusier's Ronchamp, you could be certified and locked up for raving. In architectural design, the interest lies in more or less controlled departures from the norm. Here, inexactitude holds a fascination.

The spirit of architecture thus seems antithetical to that of engineering, the two coming together only imperfectly. Intuition, magic, eccentricity, unfulfilled yearnings -- architecture is a mirror of the imperfect human life. Its beauty sustains us; its heavy scent makes us drowsy. It heals us, much the same way as our own dreams heal us every night.

If we accept that the Two Cultures represent two fundamentally different ways of viewing and understanding reality, then each camp might perceive environmental tempering in the following ways: A classical understanding would see the environmental control system -- the wires, the pipes, the ducts -- primarily as underlying form itself. A romantic understanding would see it primarily in terms of its immediate appearance. If you were to show a mechanical drawing or schematic to a romantic, it is unlikely he would see much of interest in it. It has no appeal because the reality he sees is its surface. But if you were to show the same blueprint or schematic or give the same description to a classical person, he might look at it and then become fascinated by it, because he sees that within the lines and shapes and symbols is a tremendous richness of underlying form. [Pirsig, p 66-68.]

The Romantic mode is primarily inspirational, imaginative, creative and intuitive. Feelings rather than facts predominate. Art when it is opposed to Science is often romantic, since it does not proceed by reason or by laws, but rather by feeling, intuition and esthetic conscience. In the romantic conception, truth takes shape in the mind of the observer: it is his imaginative grasp of <u>what might be true</u> that provides the incentive for finding out, so far as he can, what <u>is</u> true.

The Classical mode by contrast, proceeds by reason and by laws which are firmly embedded in tradition. Truth resides in nature and is to be got at only through the evidence of the senses: according to Medawar, apprehension leads by a direct pathway to comprehension, and the scientist's task is essentially one of <u>discernment.</u> This act of discernment can be carried out according to a Method which, though imagination can help it, does not depend on the imagination: the Scientific Method will see him through. [Medawar, 1967, p 118.]

Each of these modes of reasoning is poorly appreciated by members of the opposite camp. The lines of understanding are firmly drawn and not easily crossed over; according to Pirsig:

> There is a classic esthetic which romantics often miss because of its subtlety. The classic style is straightforward . . . unemotional, economical and carefully proportioned. Its purpose is not to inspire emotionally but to bring order out of chaos and make the unknown known. It is not an esthetically free and natural style. Everything is under control. Its value is measured in terms of the skill with which this control is maintained. [Pirsig, p 66-68.]

One can construct a table which characterises the two major views of reality and assign to each the architects whose work bears the mark of that approach to design. Unification of these separate visions of reality seems to occur without regard to alignment in the Romantic/Classical spectrum.

C L A S S I C A L

Universal principles and laws -- establishment of ideal fixed forms. Objective. Impersonal. Generalities, types, ideals, standards. An imagined standard of humanity. 'Meaning;' Gropius, Mies van der Rohe, Le Corbusier, Kahn, Stirling.

R O M A N T I C

Freedom of individual expression and character -- likes things remote and mysterious. Subjective. Personal. Expression of individual emotion, adventure and experience. 'Lyricism;' Mendelsohn, Wright, Mackintosh, Aalto.

The philosophical location of a designer on the Classical / Romantic spectrum can be interpreted from his statements and his works. Maxwell Fry remarks on the allegiance of Le Corbusier to art:

> Corbusier said to me one day that he was interested only in art. I felt this in his persistent withdrawal from what might be called vulgar contact, the ordinariness that makes up the bulk of mankind and is both its strength and weakness. [Walden, p. 350.]

But the interpretation could be modified and is perhaps contradicted by Le Corbusier's own statement:

> Structural systems determine architectural systems. Technical processes are the very abode of lyricism.

Scientific knowledge can contribute to human perceptions and qualities to form the nucleus of a sensibility. One example is J.G. Crowther's account of his tour of the Kremlin in which the evolutionary relationship between form and function is hammered into his consciousness. In the museum he saw a series of:

> . . . drinking-vessels of the medieval Tsars, which became smaller as the centuries passed and technique advanced so

that vintners learned how to increase the alcoholic content of wine and enable a smaller quantity to produce an equal effect. [Crowther, 1924, p 154.]

It is a commonsense deduction which might not have occurred to a literary/artistic mind, which might have thought the change was a movement in the history of aesthetic taste. This allegory not only throws an ironic light on the sequence of goblets, but also compresses a whole range of human history into manageable size.

A theme which has been pursued by Jencks in his Le Corbusier and the Tragic View of Architecture is the sexual connotation of some of the signs or elements of Le Corbusier's design vocabulary. [Jencks, 1973.] There is also a sense in which the Two Cultures assume secondary sexual characteristics, and to some extent polarise all men's intellectual natures into masculine and feminine. By this reasoning the 'complexity' the poet prizes has a feminine character to it. Poets and novelists, critics and teachers of literature, artists and architects, are all in some sense forced into a feminine role by contrast with scientists. It is implied that theirs are the domestic arts, like embroidery.

Even in peace-time, as Father Gerald Vann says in The Paradise Tree, Western civilization stresses the masculine -- which he identifies quite explicitly with the scientific and technological -- at the expense of the feminine-reflective -- which can be identified with the literary and aesthetic--as a creative social force. [Vann, 1954, p 56.] It is, of course, science, not the arts, which is allied with war and industry and transformations of the environment. Architecture alone is the most masculine of the design arts, leaving a monumental mark on the landscape long after its creators are gone.

Summary

An examination of the theory of design of the well-tempered environment ultimately returns to the relationship of science to art and exposes the division which exists between these two cultures. The origin of romantic and classical thinking during the Renaissance lays the groundwork for the development of scientific principles of design along systematic lines. However, artistic, lyrical expression can be found in the masterworks of the most rational schools. The architecture of successful environmental tempering seems to embody both scientific and artistic expression; elements of the Classical and the Romantic can be identified in prototypes of architecture shaped by environmental forces. The modern masters in architecture achieved a resolution between the Two Cultures by synthesising art with the new science of environmental control in their work. The architectural statements in which science and art establish a dominant aesthetic tone will be examined in succeeding chapters.

Having raised these questions about the relationship of art and science to the design of the well-tempered environment, we must now move on to an analysis of masterworks of the genre. We will return to the theme of this chapter at the conclusion of the thesis.

5. Frank Lloyd Wright: Power Applied to Purpose

Frank Lloyd Wright in his maverick midwest U.S. style was one of the first moderns to employ environmental forces which impinge on buildings as generators of architectural form. Throughout the early and middle years of his career, one finds an architecture -- first organic and then Usonian -- which celebrates the environmental management of light, heat and air.

Wright's canon of organic design was not a Thoreauvian utopia. He shared the American belief of his time in the blessings of technology. In 1901 he wrote:

> This thing we call the Machine, is no more or less than the principle of organic growth working irresistibly the Will of Life through the medium of Man.

His concept of a house as a machine parallelled that of Le Corbusier. Wright wrote that:

> . . . a house is a machine in which to live but architecture begins where that concept of the house ends . . . . All life is machinery in a rudimentary sense, and yet machinery is the life of nothing. Machinery is machinery only because of life. [Wright, 1953, p 215.]

But machine products, he believed, must be a part of a total environment designed by artists. He insisted on control over the design of all details down to the dinnerware, carpets and curtains -- he even wanted to re-design the telephone. He defined organic architecture to include the design of environmental control systems. To him, the design of an organic architecture made it quite impossible to consider the building as one thing, its furnishings another and its setting and environment still another. The spirit in which these buildings were conceived required that all these together work as one thing. All were to be studiously foreseen and provided for in the nature of the structure. These forces -- light, heat, sound and air movement -- became mere details of the character and completeness of the design concept.

He often assumed the self-assured heroic role of 'lord of creation' in designing the total environment. His desire to take complete control is revealed in a letter in 1936 to an apprentice trying to supervise the construction of 'Fallingwater.' Wright suggests that dynamite could be used to blast a plunge-pool beneath the house -- a summary way of modifying nature. [Wright, 1982, p 148.]

His disdain for the Modern movement set him apart, secure in the strength of his own creative genius. He spoke about the handling of light in 'the other' modern architecture, which he referred to as:

> . . . bald commonplaces wherein light is rejected from blank surfaces or fallen dismally into holes cut in them.

His own architecture was 'true modern architecture,' defined in terms of environmental tempering as one in which man was once more brought

> . . . face to face with nature's play of shade and depth of shadow seeing fresh vistas of native creative human thought and native feeling presented to his imagination for consideration.
>
> In true modern architecture . . . the sense of surface and mass disappears in light, or fabrications that combine it with strength. And this fabrication is no less the expression of principle as power-directed-toward- purpose than may be seen in any modern appliance or utensil machine . . . modern architecture affirms the higher human sensibility of the sunlit space. Organic buildings are the strength and lightness of the spiders' spinning, buildings qualified by light, bred by native character to environment-- married to the ground. That is modern! [Wright, 1953, p 215.]

In the early years of the 20th century, few architects in Europe could handle the new mechanical and electrical services with the same fluency as Wright. One was Eric Mendelsohn, particularly in his Universum Cinema, Berlin, 1928. Auguste Perret was the first European architect to achieve complete integration of mechanical services within the fabric and structure of the building in the Museum of Public Works, Paris, 1938. Perret's Theatre des Champs-Elysees, 1913, had been the first building to be entirely illuminated by concealed lighting. [Collins, 1965, p 236.] Perret's church, Notre Dame de Raincy represents the power of the symbolism of environmental control by placing the center of the heating system beneath the crypt of the martyrs (Fig. 5.1). Pierre Chareau and Bernard Bijvoet's d'Alsace House Maison de Verre Paris, 1928-1933, has been contrasted with Wright's work and was typical of the unrelaxed European approach to mechanical and electrical systems. [Banham, 1975, p 35.]

Japanese Influences

In addition to his acknowledged borrowing from Classical Roman technologies, the influence of Japanese design is seen in the environmental character of Wright's domestic architecture. Investigation shows the relationship between the indigenous Japanese styles and the plan of Wright's Usonian houses. Although Wright's mentor, Louis Sullivan, had used Oriental motifs earlier, the timber and plaster Japanese building at the Columbian Exposition of 1893 in Chicago made a great impact on Wright and other sensitive architects. This building, called the Hoo-den, was featured in the Inland Architect in 1892 and stood for fifty years after. Architects adapted such elements from the Hoo-den as its horizontal lines, windows in banks, and widespread low roofs. The Hoo-den and an earlier Japanese Pavilion in Philadelphia had helped to create a tremendous vogue for a 'Japanese style' in architecture and the design arts in the Eastern United States, and the development of a solid indigenous architecture in the midwest.

In 1896, Lafcadio Hearn described the 'Genius of Japanese Civilization' as being the extraordinary mobility of the Japanese in every sense of the word. Japanese living contrasted with the white man's constant search for stability and dependence on all sorts of worldly goods. The Western house was constructed to endure. But in Japan everything was in motion. The land itself was perceived as a land of impermanence. The average Japanese was not bound to any definite spot. These customs seemed to find resonance with Wright's early search for simplicity and purity of function:

> The ability to live without furniture, without impediment, with the least possible amount of neat clothing, shows . . . the advantage held by this Japanese race in the struggle of life; it shows also the real character of some weaknesses in our own civilization. It forces reflection upon the useless multiplicity of our daily wants. We must have . . . glass windows and fire; hats, white shirts, and woolen underwear; boots and shoes; trunks, bags, and boxes; bedsteads, mattresses, sheets, and blankets: all of which a Japanese can do without, and is really better off without.
>
> Think for a moment how important an article of Occidental attire is, the single costly item of white shirts! Yet even the linen shirt, the so-called 'badge of a gentleman' is in itself a useless garment. It gives neither warmth nor comfort. It represents in our fashions the survival of something once a luxurious class distinction, but today meaningless and useless as the buttons sewn on the outside of coatsleeves. [Rasmussen]

It was around 1900 that the early Japanese influence on Wright was seen in two houses built in Kankakee, Illinois. [Lancaster, 1983.] These two houses are Japanese in their intimacy with nature, inconspicuous entrances, and asymmetrical massing, as well as in the plastered terrace walls with wood copings, slender timber bands in stucco on the vertical planes of the houses, and reduplication of deep obtuse gables, which are thin and thrust outward at the peak as in some Shinto shrines.

Wright's first visit to Japan was in 1905, in order to collect Japanese prints but his interest quickly shifted to a study of Japanese domestic architecture:

> I saw the native home in Japan as a supreme study in elimination -- not only of dirt but the elimination of the insignificant. So the Japanese house naturally fascinated me and I would spend hours taking it all to pieces and putting it together again. [Wright, 1977 p 219.]

The Shinden style of residential architecture which Wright saw is important for its spatial quality derived in part from its approach to environmental tempering with structural airy lightness and well thought-out use of materials. The Japanese house consisted of a main central room, around which the whole symmetrical rectangular layout extended. Only in the garden did the overall rigorous symmetry become deliberately -- but nevertheless carefully -- disrupted. The environmental effects made possible by this style were due in part to the form of the roof and the wall openings. The Chinese influenced saddleback roof had disappeared in Japan to make way for the hipped roof style. The slope of the roof stopped short of the ridge, thus forming a small pediment, with openings through which air could pass into the attic. In connection with this the outer walls had shuttered openings at their upper level -- which constituted a fifth of the total building height -- to let out 'bad air and evil spirits.'[Pothorn, p 177.]

Wright found even the utility rooms pleasant. His later use of the kitchen as the central exhaust for his own houses may be found here:

> And the kitchen? Go down several steps to find that, for it is tiled flat with the ground and also goes high up into the rafters for ventilation. It is like a cool, clean, well-ventilated studio. [Wright, 1977, p 220.]

In addition to the roof form and the ventilation and lighting schemes, two features in the traditional Japanese home which may have been carried through in Wright's work are the _toko_, which might be freely translated as the 'picture alcove,' and the _tana_ -- an alcove adjacent to the _toko_ with shelves and little wall cupboards fitted with either sliding doors or drawers. The _toko_ is in effect a shrine where the family performs Buddhist rituals. Its floor is about a foot higher than those of the other rooms; Hanging from the wall at the back is the _kakemono_, a scroll painting with a figure and some holy text (Fig. 5.2).

Wright liked the Japanese way of life he had found in these buildings; he liked sitting on the floor, and he liked the easily adjusted, loose Japanese clothes. It is interesting that after he went to Japan the tall, straight-backed chairs he had used disappeared in favour of low seats. To Wright the elimination of the insignificant led to grace and purity. That houses were planned from the inside out confirmed his conviction that the Japanese system was superior to the traditional method in the West. In the Japanese house, he found sympathy with his concept of organic architecture. His own ideas about growth and form were reflected in certain unique Japanese words:

> there are many words like the word _edaburi_ which, translated as near as may be, means the formative arrangement of the

> branches of a tree. We have no such word in English; we are not yet sufficiently civilized to think in such terms, but the architect must ... learn to think in such terms.... [Wright, 1908, p 156.]

In contrast to the West, he felt that art and architecture in the Orient were suffused with the qualities of life. Wright had come to recognize this through his study of Japanese prints and architecture, and it corresponded with his own first rule, namely that:

> buildings perform their highest function in relation to human life within and the natural efflorescence without .... [Wright, 1908, p 156.]

Wright in later years was able to trace the Oriental origins of his own ideas back to the Chinese philosopher Lao Tze, to whom he ascribed the principle at the center of his modern designs. This principle was:

> ...that the reality of the building consisted not in four walls and a roof but inhered in the space within, the space to be lived in ... my own recognition of this concept had been instinctive; I did not know of Lao Tze when I began to build with it in mind; I discovered him much later ... quite by accident ... and ... for some time I felt as a punctured balloon looks. [Wright, 1938, p 4.]

Lao Tze, an older contemporary to Confucius, has but one short essay attributed to him. It is called the Tao-te-ching, the Reason-Virtue Canon. The verse states that the usefulness of certain things depends not upon that which tangibly exists but upon what does <u>not</u> exist, citing the axle-hole of the wheel, the hollow inside of the clay pot, and the empty volume of a house. Taoism is sensitive to the intangibles of space and light. Instead of perceiving a building as shaped by solid material, the writers of the Tao Te Ching say,

> Cut out the doors and windows in order to make a room. Adapt the nothing [meaning the empty spaces] therein to the purpose in hand, and you will have the use of the room.

As the testament of Taoism, the Tao-te-ching became well known to all the peoples of Eastern Asia, including the Japanese, who adopted the reading and writing of Chinese characters, and its terse wisdom became deeply ingrained in their thinking. The West did not accept a concept of architecture so radically different from its own during the period of Chinese Taste, but got it from the Japanese -- instinctively or otherwise -- at a later date.

Wright felt that America provided the best ground for his brand of architectural Renaissance because the American 'is a pioneer in every right sense of the word' and not faced, as are the English and Europeans, by 'traditional forms which they are in duty bound to preserve.' An American, he stated,

> is in duty bound to establish traditions in harmony with his ideals, his still unspoiled sites, his industrial opportunities, and industrially he is more completely committed to the machine than any living man. It has given him the things which mean mastery over an uncivilised land, comfort and resources.

It is interesting to theorise about the development of a modern, space- and light-oriented style in the architecture of Wright. This style did not develop in England until much later; one speculative reason was that in the early 20th century, the taste- setters in England were still the aristocracy, who stood to lose much of their power and influence to the nouveau riche. They were not very appreciative of the aesthetic potential of a new technology that bore a negative influence on their own lives. On the other hand, the midwestern American who was making money through technology was free to appreciate the aesthetic beauty of technology as well. He was himself a taste-setter, being unchallenged for social position and power in his own territory, whereas the English industrial entrepreneur had to try to achieve status with his money by copying the tastes of the aristocracy. [Wilmott, 1973-74, p 44-54.]

In England, the development of the Arts and Crafts Movement -- which attempted to preserve high standards of craftsmanship and to counter the influence of the machine -- can be seen partly as a reaction to the de-humanisation brought about earlier by industrialisation, and as an expression of resistance to technology. The impact of industrialised technology had been much softer both in the Netherlands and in the United States and the evidence is seen in the architecture of both these countries.

In the midwest U.S. there was little resistance to technology from craftsmen, because a crafts tradition hardly existed. However, there was an abiding interest in the crafts, and a Chicago Arts and Crafts Society was formed with links to the English Arts and Crafts Movement. But the Americans seemed not so much interested in rejecting the machine as in integrating the craftsman into new roles made possible by the developing technology. For example, the byelaws of the Chicago Arts and Crafts Society listed as one of its goals 'to consider the relation of the machine to the working-man.' [Brooks, p 19.] The favourable attitude toward the machine in Chicago is also shown in the formation in 1899 of the Art Industrial League, whose purpose was to establish a training program for industrial designers. Workshops were set up and instruction given in the industrial arts. This is not surprising since people were close to a frontier culture where, because things are 'hand-made' of necessity, the 'ready made' was appreciated and status was granted to those who could afford to buy manufactured items. Thus Wright's early celebration of technology rested on a supportive cultural base in his homeland.

Technological development around the turn of the century in the Netherlands can be compared to that in the midwest U.S. In both locations, space- and light-oriented architecture came out of highly developed urban environments. The Netherlands has one of the highest population densities in the world, and space is at a premium in the cities. The midwest U.S. may have been relatively unsettled at the turn of the century, but Chicago was a crowded city. In urban centres, high real estate prices forced even the rich onto small lots for their houses and forced them to 'discover' the skyscraper for their businesses. The expansive 'prairie' houses with their horizontal lines were not meant to be urban however, but suburban. In both the Netherlands and the midwest U.S., the world beyond the crowded city was relatively accessible, and had a strong influence upon architects. Both of these extra-urban environments were visually similar in their open, largely cultivated flatness, the sky reaching down to the land.

Water is also an element important to both locations. The Netherlands' relationship to the sea is pervasive. Chicago faces the inland sea of Lake Michigan. Nature presents itself in these environments as unhindered horizons flowing with unbordered space and light. It is a landscape primarily man-shaped except for the vastness of sea and sky, forces that are space-and light-bearing as well as non-figurative or abstract. The effect of this sort of nature upon art is seen in the work of Vermeer and Mondrian. It is revealed in Wright's architecture by a space and light orientation which accelerated as technology made possible unsupported walls and large windows. In the near-urban environment, where real space and light are at a premium, the creation of a sense of space and light in buildings by Wright was especially appropriate.

The Inglenook

The evolution of the inglenook as a form-generating element with environmental meaning in Wright's architecture took place within a relatively few years; first in his home and studio, continuing over the next twenty years through the Usonian House stage of his career. Its sources for Wright were both Oriental, from the toko and the tana, and European. The inglenook as an architectural element in the West can be traced back more than 400 years, to its origins in the English medieval house.

Special places for intimate and comfortable gatherings of friends and relatives were a part of the English vernacular style as early as the 14th century. [Wood, 1981.] The inglenook as a distinct architectural element related to the fireplace can be clearly identified by the late 15th century. Its beginnings in the larger houses of the time were probably as seating of some kind, arranged within the great chimney breast of a working kitchen, sheltering one or two people, perhaps servants as they prepared food, from the prevalent cold. It slowly changed to a more appropriate form which was probably like a window embrasure, located in the fireplace of the main hall, where it could be enjoyed by the entire family and also by privileged guests brought into the family fold.

An independent development in smaller homes, the centrally located fireplace -- not necessarily with an inglenook incorporated -- can also be traced to its early origins. M. W. Barley writes that,

> The one novel and very economical development of this age [medieval times] was to put the fireplace (or two back to

> back) on the axis of the house, so that the stack broke through the roof at the ridge. In a storeyed wing four flues could be accommodated in one stack, and this admirable idea, which probably originated in London in mid-Tudor times, had spread to Wales by the end of the 17th century, and to the level of the small farmhouse. [Barley, 1963, p 36.]

Smaller colloquial countryside houses of the 19th century, although simple, nearly always had a comfortable fireplace that projected from the wall on the outside. According to Muthesius,

> it was shaped like a small bay, the long side of which formed the hearth, while at either side were two little windows bringing direct light to the seats that flanked the hearth. [Muthesius, 1979. p 16.]

It was socially and functionally important in the earlier forms that the seats placed to the side of the fireplace have direct light to enable people to sit and read, converse or sew while there. Therefore, an outside wall was the most frequent location for such a space (Fig. 5.3). The alcove or inglenook formed a jutting extension which was a familiar form in the external appearance of the houses of that time. The oriel, a related, expressed exterior form with a special interior function, was also found in larger houses from the 15th century onward (Figs. 5.4, 5.5, 5.6).

These special places were not stylistically or socially popular during the period of Romantic Classicism of the 18th and 19th centuries and their use declined. There were some exceptions, the most notable being the Reform Club by Charles Barry, London, 1838-40, where there is an inglenook on each main floor, one Corinthian, the other Ionic. At the time, Barry excited considerable admiration for the amount of mechanical equipment incorporated into the Reform Club, which included steam heating, gas lighting, an intricate system of bell-wires, widely distributed hot and cold water, and a number of service elevators. [Kaufmann, 1980, p 145.]

In the late 1800's, Eden Nesfield, Norman Shaw, M.H. Baillie-Scott, and others were responsible for reviving the idea of the inglenook -- or 'cozy corner,' as it was then called -- in their residential architecture. Typical arrangements are seen in the architecture of both sides of the Atlantic (Figs. 5.7, 5.8, 5.9,5.10). The outstanding examples in those years were probably Shaw's house, Three Gables, at Hampstead and Baillie-Scott's Blackwell, on Lake Windermere. Baillie-Scott in particular, whose plans have often been compared to those of Frank Lloyd Wright -- by those who would like to find in his work the origins of the 'open plan' -- was always most careful to provide plenty of ingles and enclosed talking spaces. In Blackwell, there are five separate inglenooks and three oriels (Figs. 5.11, 5.12,5.13). Few large dining rooms of the late 1800's were without an inglenook, as a casual examination of the figures in The English House will reveal. In fact, Muthesius lamented:

> Some architects tend to overdo the notion; in some houses every fireplace has its recess . . . . [Muthesius, p 188.]

As it happens, several masters of the middle-class house -- Newton, Voysey, Baillie-Scott, Baker, Dawber, Frank Lloyd Wright and Lutyens -- started their careers in the 1890's although there was a wide discrepancy of age between them. Running through all their work was a strain of the Vernacular style, itself a child of the Arts and Crafts Movement, which formed the basis of most English -- and a lot of American -- design right up till the 1950's. One of the architectural elements common to all of these designers was the inglenook.

The difference in the plans of Wright and the English architects can be directly attributed to the different climates. In the hot summers on the Chicago prairie it was a positive advantage to have great open rooms with porches, which were neither inside nor out, but which caught every breath of fresh air going. In the cool damp climate of England, cosiness was born of necessity. The sense of enclosure given by a small room within a room, warmed with a great wood fire, womb-like and protective while outside the storms rage or the fog drips is one of the greatest pleasures to be had from an English house. No amount of Palladian elegance can compensate for this warmth and coziness.

Beyond function, however, the inglenook became an easily constructed symbol of genteel taste and domesticity. Smaller houses of the late 1800's had an inglenook in the form of economical prefabricated units, available from catalogues, which were installed in existing rooms as fittings and which sometimes made a caricature of the original concept. It was still the practice in the 1800's in the smaller English houses to use the dining room as a general sitting room after dinner. In the winter, since it would have been in use throughout the day, it was probably the warmest, and perhaps the only warm room in the house. In dining rooms of the usual shape of the time, with the fireplace located on the short wall, the immediate surroundings of the fireplace were easily converted to a sitting area after dinner.

Indeed, the shift of the location of the inglenook was perhaps linked to a change in after-dinner social drinking habits. Muthesius, drawing part of his information from Sheridan's <u>School for Scandal</u>, describes the evolution of social activities in this way:

> It used to be the custom in England to remove the tablecloth from the gleaming polished mahogany table even before the dessert; and after the meal the men embarked upon a drinking bout that . . . often continued far into the night. Only very heavy wines (preferably port) were consumed, and the company smoked and drank a great deal. During the 19th century men of better social standing gradually became more moderate in both respects. The English gentleman of today no longer drinks . . . so there is no longer any reason for him to ensconce himself at the dinner table for considerably longer than the woman, whom he follows into the drawing room after a speedily smoked cigar, and with whom he converses without smoking or drinking. He has in fact entirely departed from his former ways and has become 'fit for the drawing room.' [Muthesius, p 88.]

The style of the inglenook could be adjusted to compensate for taste but the essential elements of the design were standard: The wall where the inglenook was located commonly opened into the recess either with a large arch, or a simple rectangular opening under the frieze of the room. The recesses were rectangular, round or polygonal, with floors which were on the same level with the floor of the house. Built-in seats, made of wood and usually covered with cushions, lined the walls of the alcove. Inside the anthropometrically designed alcove, a person usually had just enough room to stand upright. Muthesius was of the opinion that this space was the exact equivalent of the old German tiled stove surrounded by stone seats, however it seems to have more of a feeling of intimacy than its German counterpart.[Muthesius] Certain architects, George Walton and Charles Rennie Mackintosh among them, made the fireplace itself a sort of seating place more in keeping with the German aesthetic, by raising the hearth to chair height and by providing seating on either side (Fig. 5.14). Even when the fireplace could not be designed in a recess, the area around it could be built up to simulate a recessed inglenook by surrounding it with a fixed wooden or masonry wall appearing either as a low partition or reaching to the ceiling. A design for an inglenook appears in the drawings of Adolf Loos around 1900 which he built as part of his studio in 1903 (Figs. 5.15, 5.16).

A major theme of 19th century builders in midwest America had been the independence and protective quality of each home. One of the visual references in the home which seems to be drawn from Ruskin was the fireplace. More than other architectural details of the time, the symbolic meaning of the fireplace was clear, since the widespread use of furnaces and stoves actually made fireplaces unnecessary for the provision of warmth. The image of the family gathered around the hearth was the most common way to call up the ideal of the home as a place of protection and communality. Use of this device by fashionable English and American architects ensured their great popularity in both countries at the time and helped stir a vogue for large central fireplaces.

The important point to make is that the appeal of the fireplace as not functional but evocative. The power of environmental control as a symbol of protection, domesticity and community evolved to its logical limit in the designs of Wright. Whether consciously or not, Wright developed the strength of subliminal suggestions of the hearth and chimney as deeply rooted reminders of family stability.

In the years preceding Wright's discoveries, there were an abundance of professional references explicit to the subject. John Pickering Putnam, a Boston architect, published a historical survey of the fireplace in 1881 which stressed the social function of the hearth as a gathering place for the family. He described the great variety of furnaces, mantels, grates, and cleaning equipment to supplement and adorn fireplaces that was then available on the market. [Putnam, 1881.] Frances LeBaron extolled the fireplace as the soul of the living room in an article which Wright could have read, 'Mantels and Grates,' which appeared in 1884 in the Inland Architect and News Record. [LeBaron, 1884, p 36.]

As methods of industrialisation and standardisation became more and more common, certain elements in the home were simplified or even eliminated, but the fireplace was one of many architectural symbols that had to appear in every house; the rhetoric of diversity was modified by many such standard items. Given the range of equipment available, it is not surprising that there soon appeared, in middle-class homes, more than one way to present the fireplace. The parlour or sitting room, wherever the family came together for the evening, remained the first choice and the most majestic space in the house. But there were also cozy, tiled fireplaces for the mother's bedroom, where her children were welcomed into her special affectionate realm. Other builders began to imitate the wealthy family who placed the staircase and fireplace in a formal living hall, so that its message would be visible to every visitor.

Blessings or mottoes were sometimes carved into the surface of the carved wood or stone mantel, perhaps with a portrait of a child at the center. The principle was always the same. The symbolic purpose of the prominent fireplace was to declare that while visitors were welcome, the family was the focus here.

Equally important for privacy were the numerous small niches scattered through the house: the bay-window seats and inglenooks by the fireplace, alcoves and porches, attics and small side yards, all the intimate spaces we associate with the late Victorian dwelling. These provided opportunities for retreat, even in the very rooms that were supposed to foster family unity. In particular, the parlour and sitting room were provided with these private cubbyholes for seclusion. Here an individual could sit apart, while being with the family. Like the ideal of personal expression through industrialised building materials, this was a clever compromise. It was possible to have the image of a harmonious family and still provide for withdrawal from cloying togetherness. Delicate balances such as these characterised the Victorian builders' fiction of the model home.

In spite of the endurance of the fireplace in the home, the most conspicuous improvement in domestic building technology in the late 1800's had been in heating and plumbing fixtures. Basement hot-air or hot-water furnaces, connected to a maze of flues and registers, were available but still fairly expensive in 1880. Furnaces had to be frequently stoked with coal, and the register in each room adjusted by hand until automatic controls became available in the early twentieth century. Even though these systems were troublesome as well as expensive, they were often displayed as proud possessions and works of art. Wherever located, heating appliances were encrusted with ornament to make them artistic. The popular Crown Jewel and Art Garland stoves were advertised as beautiful objects.

Other architectural improvements brought in light and air. However, there were yet a few comfortable dark corners to be found. Numerous writers on the home still praised the fireside inglenook as a cozy place for comfort and warmth, shielded from the intrusion of cold drafts.

Wright's Inglenook

Fifteen years before the publication of Muthesius's The English House, Frank Lloyd Wright had added the inglenook to his own repertoire. His style and content was probably initially influenced by H.H. Richardson -- whose work set the tone for American architecture in the 1880's -- and the two men for whom Wright worked, J.L. Silsbee and Louis H. Sullivan. Polygonal bays and inglenooks were a part of the Shingle Style, with its love of the whimsical element, which preceded Wright's work. Owing perhaps to Wright's minimal acknowledgement of historic reference, his first attempt at incorporating the inglenook was strikingly original.

The inglenook in Wright's Oak Park house measured three by eight and a half feet, was located at the very heart of the house, and opened to the living room to reveal to the visitor a low, round-arched fireplace of brick (Figs. 5.17, 5.18, 5.19). On each side was a severe wooden bench, covered with cushions. Wright later commented about this type of bench:

> I have been black and blue in some spot, somewhere, almost all my life from too intimate contact with my own early furniture. [Wright, 1955 p 56.]

Perhaps the most striking thing about this special place in Wright's house is its location, dead in the center of gravity of the plan. Whereas the inglenook in Shaw's and Baillie-Scott's houses had been a peripheral element on exterior walls, in Wright's work it becomes a hub from which other spaces radiated. Here is his discovery of a spatial relationship which establishes a monolithic centrepiece in the plan, from which the volumes spread centrifugally to the perimeter of the house. This radiating movement is picked up again by the advancing terrace with its low parapet to the south and to the east.

The combination of the characteristics of the inglenook with the central location of the fire was a unique contribution of Wright to the history of the shape of environmental control systems. One element was missing in his first attempt, however. It was the natural lighting which had been such an important factor in the English designs. Wright restored daylight to its proper place of importance within the interior in subsequent designs by manipulating the roof form in a way which permitted clerestory lighting. Typical of his mature designs of this period is the Ward Willits House (1901), which presaged the Robie house in its use of a centered hearth which stakes the centrifugal plan to the ground (Fig. 5.20).

Again and again in the residential architecture of Wright's 'first golden age' he relies on the inglenook core as an element from which subsidiary spaces revolve and which is also used as a subtle screen betweeen living and dining spaces permitting an 'open plan.' The inglenook, which had always been the symbol of domesticity now became the protected core of the house from which other, larger spaces radiated out to make contact with the exterior environment.

Almost all the owners of Wright's homes were pleased with their fireplaces, both as to location and function. There was a period in the late 1930s however, when Wright had a tendency to stretch the height of the fireplace opening to its functional limit. The fireplaces in the Wiley, Johnson, and Manson houses are examples. The Manson fireplace smoked sufficiently to necessitate an inspection trip by Wright and several apprentices. Wright and company promptly reduced the height of the opening by adding several courses of brick. [Brooks, 1981.]

In the morphology of the later Usonian Houses, the central hearth was the most important area, acting as both the intersection of the two functional wings -- sleeping and living -- and the point of most visual activity due to the quality of the light and the intersecting planes. Utilities, servant quarters, and almost all of the bedrooms are laid out in a thinner rectangle. This is the center of a firm core with bold and decisive, organic movement from it. Major living areas are forcefully demarcated as entities, yet by means of the open plan they flow together and conveniently relate to service areas.

The Robie House

Wright was the leading exponent of the short-lived Prairie School, America's most successful attempt to achieve a national style,a unified design. The Prairie School emerged in the first decade of the 20th century at a time of great social change. Previously the American middle-class home was a small-scale, small-budget imitation of the English country house -- backstairs, servants' quarters, butler's pantry and all. With industrialisation and urbanisation however, the servants left for factory jobs; fathers and sons and even daughters began to work outside the homestead. The household economic unit changed from producer to consumer, and wives became household managers.

Wright's response to this shift was to make the kitchen an efficient workshop and to gather the family around the hearth, as if to hold it together. Large, central fireplaces are the dominant element in his Prairie houses. Prominent chimneys stake these homes to the earth and provide structural support for the sheltering roof. The entire ground floor around the hearth is one room -- a family hall flowing from the vestibule to the living room to the dining room. It is as different from the stiff, old parlour as it is from the informal recreation room of today's suburban home. As Wright saw it, the hearth was the place both to entertain guests and to relax in family privacy. At the epitome of the Prairie style in 1910, Wright demonstrated with the Robie House a mastery of cooling in the summer and heating in winter, along with lighting and servicing schemes that were unparallelled at the time.

In the article, 'Mr Robie Knew What He Wanted,' the client's needs are frankly stated:

> I wanted sunlight in my living room in the morning before I went to work, and I wanted to be able to look out and down the street to my neighbors without having them invade my privacy . . . I didn't want any wide trim on the doorways or windows. I wanted it narrow, to bring in a wider window, to give me more light. [Robie, 1958, pp 126.]

The Robie House rises to its stated purpose by meeting all these environmental demands and more. The house successfully demonstrates the following environmental techniques (Fig. 5.21):

1. deep roof overhangs

2. deeply shaded entrance court on the north side

3. shaded ground floor, both of which combine to form a cool air tank which partly tempers the whole house in summer

4. each window can be opened for natural ventilation (Fig. 5.22)

5. One radiator per window, under french doors, radiator concealed under a grille (Fig. 5.23).

6. concealed lights controlled by theatrical dimmers.

7. heat of concealed lights pulls warm air out of the living room to the attic space to ventilate it.

8. Finally, the air is extracted from the roof space through a thermal duct built into the side of the main chimney. There is a neat pattern of gaps in the brickwork on the side of the chimney which marks the point where this well-used air is finally exhausted to the outside. [Jordy, 1970, p 198.]

The chimney in the Robie house as in his succeeding residential work, possesses symbolic as well as formal content. Acting as a formal pivot for the design, it simultaneously evokes age-old memories of the hearth at the centre of the house. The vertical thrust of the chimney reverberates in the staccato rhythms of the structural studding which rises through the composition. These vertical elements repeatedly come to the surface, to provide framing -- mullions -- for the windows arranged in long bands. The studding, like the chimney, penetrates floor and roof planes well behind their outermost edges to create an interweaving of support and supported. In Wright's words, 'fibrous integument takes the place of solid mass.' [Wright, 1954, p. 32] This arrangement provides for deep shading of the narrow glazing bands, a significant difference in detail between Wright's and Le Corbusier's treatment of ribbon windows.

Wright's planning typically depends on a winding path through varied spaces, alternately dark and light, toward the core of the house. The architecture advances to greet the visitor, so to speak, and we are already in the indistinct zone of indoors-and-out that characterises the perimeters of Wright's architecture. As one attempts to enter move forward, the second storey projects out over the court, creating a dark pocket. The door appears in the shadow, low and horizontal in feeling. The hall inside is equally shaded with faint light coming through high windows. Moving towards the core of the house, the hearth and its adjoining stairs act as the functional divider for the spaces on each floor, and also as the central anchor for the mass in which the major axes cross. Stairs beside the fireplace core recall the stairways which cling to the chimneys of the early English house.

The breadth of the chimney and the long low mantel of the fireplace represent a lateral force which counters the major dimension of the space and opposes the upward thrust of the flues. The feeling of the space has been compared to that of a railway carriage (Fig. 5.24) [Lancaster, 1956, p 211.]

Wright did not flood his interiors with light, thereby heightening the drama and effect of the carefully placed openings. By most standards the Robie House is somewhat dark. However, the strip of windows faces south and with sunlight streaming the full length of the space the interiors are saved from being sombre. The space would lose much of its life both day and night without the lighting globes which ornament the hard underedge of the dropped ceiling; they dramatise the lateral movement of the wide mouldings by emphasizing them, an example of the visual resolution of force by a counterforce in Wright's work. At night the globes gave Mr Robie the brilliant illumination he wanted in the centre of the room. In the more softly lighted area on the underside of the dropped ceiling, dim lights gleam faintly behind panels of frosted glass supported on wooden grilles -- this was 'moonglow' to Wright. From outside, when fully illuminated, the house is uniquely beautiful at night. Passing it, the bright globe appear to move behind the screen of the windows, now and again picking out bits of colour in the leaded glass. This effect has not surprisingly been likened to Japanese lanterns floating in space, or;

A yacht perhaps, lighted from stem to stern, and ready to sail.[Jordy, 1970, p 184.] Robie's son told interviewers that when he was a student at the University of Chicago, there was a legend that the Robie House was built for a sea captain, and hence made to look like an ocean liner -- long and thin, with deck-like balconies.[Architectural Forum v 109, Oct. 1958, p 210.]

It was not until after the Robie house that Wright's ventilation techniques, based on the Japanese utility room principle, began to make use of the open plan as a plenum for moving air through the house. The advanced environmental control features in both the Robie and Baker houses, were modified for greater comfort in the hot mid-West U.S. climate by creating a raised ceiling over the kitchen with clerestory windows for ventilation. Thus the kitchen space became the venting flue for the social portion of the house. As one owner remarked:

Best damn cocktail party house in the neighborhood. You open those vents and all the smoke drifts to the kitchen and disappears. [Brooks, 1981, p 42.]

Another modification in Wright's later houses was heating by hot water circulating in pipes beneath the slab. This furnished satisfactory heat in mild climates, and in northern areas as long as only throw rugs were used. However, when wall-to-wall carpeting was laid, as it was in several houses, this acted as an insulating layer, preventing heat from reaching the living areas. Eventually supplementary skirting board heating was added in these homes.

The design and operation of the pioneering under-floor heating scheme is probably best described from the point of view of the, owner-occupant, Loren Pope:

Radiant heating was a virtually unknown thing at that time. Everybody thought we were crazy to lay wrought iron pipes under the floor. They kept asking, 'What if there is a leak? You would have to dig up the whole slab.' However, all the pipes were tested for almost a week at approximately 120

> pounds of pressure. The normal operating pressure of the system is only 11 pounds, so we had tested far above the maximum that would ever be required. Then we had crushed stone laid around the coils to prevent damage when the concrete was being poured. [Pope, 1948, p 32-34.]

Pope, typical of many clients who showed remarkable faith in Wright through the realisation of his revolutionary designs, shrugged off all the negative advice he received during construction:

> There had been predictions, too, from men who claimed, actually to be heating engineers, that the radiant heating wouldn't work. There were others who said that the walls would be cold on the inside; and that the concrete floors would be a dry lake of condensation in the summer and a rink of frost in the winter. The other predictions were just as silly. The walls were never cold to the touch inside; there was never a drop of condensation, a crystal of frost, or any other moisture on our floors...there is no cleaning of streaked and sooted walls because radiant heat is clean heat. [Pope, 1948, p 32.]

Pope showed his enthusiasm for Wright's ideas -- typical of Wright's clients -- and a sophisticated knowledge of the attributes and operating principles of radiant heating. He may have been a better advocate of the system than the architect himself, to hear his story:

> In this house, even the dog stays off the furniture -- he prefers to sleep on the warm floor. Now it's important that you understand about the warm floor. After living with radiant heat for six years our family will be satisfied with no other. There are warm floors on cold winter mornings. The air temperature is much lower than with other systems, which means it is never stuffy or uncomfortable.
>
> The principle of radiant heat is that a warm surface does not absorb your body heat, hence you can have a lower air temperature. For example, we kept our thermostat at 63 degrees. Seventy is far too warm. And, with this system, the temperature is constant. From a design standpoint, radiant heating was marvellous because getting rid of radiators -- then almost universal -- reduced visual disturbance. [Pope, 1948, p 32.]

The floor construction of Wright's Fallingwater is the environmental descendant of earlier homes and is the result of some of some of the lessons learned in the design of his radiant floor heating techniques. Fallingwater had insulation spacing provided by the unique configuration of the floor structure:

> Each concrete tray is structural on its lower surface; above this, in many areas, is an air space divided by small concrete walls that support a wood floor, finished in flag stones from the nearby quarry. This captive space allows the stone floors to be well insulated and comfortable even to bare feet. [Wright, 1962, p 20.]

In Wright's house designs, the schemes for both natural and artificial lighting were in harmony with their organic character. The lighting fixtures were designed to either be integrated with the structure or to reflect in their form certain principles then important to Wright. For instance, the pendant lighting fixtures in Brown's bookstore demonstrate the effect of 'breaking the box' with the four screens around the light source opened at each of their corners (Figs. 5.25, 5.26).

In the design of lighting for his houses, he shunned the use of chandeliers in favour of concealed lighting. He used lights mounted on brackets when necessary because of low ceilinged rooms. In a letter he explains how his early gas and electric lighting worked:

> [Walter Burley] Griffin has just gotten up a scheme for a combination bracket fixture like this . . . the case or lantern lifts off. When in place it conceals the lights within. These fixtures will contain gas and electric, or two electric lights, distributed about the room, the combination cannot be recognized from the electric lights. The lantern can be lifted off to light the gas. This provides for gas lighting, and still all the fixtures are the same in appearance throughout the house. [Wright, 1971, p 104.]

In the Pope-Leighey house, which was typical, most of the lighting was built in. Loren Pope, in his 'Love Affair of a Man and His House' describes the installation of incandescent bulbs recessed in the overhead trough along the side of the living room. [Pope, 1948, p 32.]

The Pope-Leighey House lighting scheme is explained by a Taliesin Fellow in the context of organic design:

> Built-in lighting, cabinets and bookcases have the same effect. . . [they] contribute to the sense of unity, as does the use of the same wall materials inside and out. In a small house you sense more space when not distracted by extraneous objects, especially here where the interior is kept consistently to horizontal lines and soft natural colors. [Chadwick, 1969, p 63.]

Pope's daughter described the almost metaphysical effect which the well-integrated natural lighting in the house had on her:

> That it could have feelings, as well as a feeling, arises from its real union of the outdoors with the inside, from the glorious, ever-changing play of patterned sunlight upon the walls.[Leighey, p 59-62.]

The natural lighting and opening of corners with well-placed glazing was described by the owner as:

> . . . not only the 'bringing of the outdoors in' but an actual oneness of the two, not just light in a room but the vivid joy of warm light that moves even as the sun moves. [Bullock, p.66]

<u>Environmental Control in Larger Buildings</u>

Wright traced his development of an environmental architecture from its early roots. He attributed the environmental effects achieved in his larger buildings to their beginnings as ideas in his early residences. About the Guggenheim Museum, which had been conceived in part as a great eye-on-the-sky, he had this to say:

> The museum is itself a lighting project. It exists in the top lighted end of the little kitchen, Taliesin North. [Wright, 1982]

One of the simple beginnings of architectural form related to ventilation and top-lighting can be seen in the design of the kitchen of the Jester House, constructed in 1980 at Taliesin West from plans dating from 1936 (Fig. 5.27).

Before the turn of the century, Wright also experimented with the then high-technology means for introducing daylight into office buildings being introduced by the Luxfer Light Prism Company (Fig. 5.28). Wright had an exclusive franchise for the use of this patented system in the midwest U.S. and he designed a skyscraper for the Luxfer Company in 1895.

Wright had the chance to translate his residential concepts of open planning into monumental form in the 1904 Larkin Company Administration Building. Wright's reputation had reached the Netherlands and his works were beginning to draw visitors from abroad. The Larkin Building, located in remote Buffalo, New York, was one of the buildings that Hendrikus Peter Berlage examined in 1911 to verify for himself the reports on Wright's power as a designer:

> Having been told that Wright's masterpiece was the Larkin Company Office Building in Buffalo . . . I went to see it and must confess that this is an understatement. The head of the office works at the same table as his employees, and from his table his view encompasses the entire room with its various floors which, like galleries, surround the central hall. This hall has excellent light in spite of the large brick masses that form the exterior corner towers; indeed, the effect is similar to Unity Temple where the corner staircases are lighted from inside. [Berlage, 1912, p 165-167.]

Berlage had thus identified the environmental effects in lighting and air-handling which led to freedom from the limitation of the box-like enclosure of space typified by fixed vertical and horizontal planes. Wright was successful in achieving this in both the Unity Temple and the Larkin Building. Interestingly, this was a turning point in the professional life of Wright which had a parallel in the career of Le Corbusier several years later.

It was almost seven years after Wright's 'destruction of the box' that Walter Gropius and Adolf Meyer in the Fagus Factory demonstrated the remarkable ability of glass and light steel, pseudo-curtain wall construction to enhance the feeling of spaciousness at the edges or intersections of the wall planes (Fig. 5.29). [Wright, 1955, p 75.] Wright had felt a need for the 'liberation of interior to outside space' along these edges. His discovery depended upon the fact that the most economic support of the horizontal elements of the building is at some point inside the exterior limit. It came some ten years earlier than Le Corbusier's Dom-ino proposals, which were based on the same logic.

Wright describes his strongly independent pioneering work in An American Architecture as a conversion 'from box to free plan' and a discovery of an architecture that is 'space instead of matter.' [Wright, 1955] He graphically describes ways of manipulating the wall elements, which he called the 'four screens,' so that any combination of openings is possible in any direction.

His struggle for the discovery of these principles came early in the development of a design for the Larkin Building (Figs. 5.30, 5.31). This design was, he said,

> Power directly applied to purpose, in the same sense that the ocean liner, the plane or the car is . . .[Wright, 1955]

Success in achieving the volumetric relationships he wanted in the design for the Larkin Building was not easy or assured until the very end. He describes the pathos of the possible failure of his design and the drama and joy of victory at the last moment:

> The solution that had hung fire came in a flash. I took the next train [from Chicago] to Buffalo to try and get the

> Larkin Company to see that it was worth thirty thousand dollars more to build the stair towers free of the central block, not only as independent stair towers for communication and escape but also as air intakes for the ventilating system . . . . Mr. Larkin granted the appropriation and the building as architecture, I felt, was saved. [Wright, 1955, p 143.]

Unfortunately, the Larkin Building no longer stands. However, many early admirers and critics saw the environmental effects which were un-precedented in an office building and we must depend on them for a description. Jan Wils was stunned by the spatial effects he witnessed:

> Daylight enters through a skylight over the inner court, and through windows between the piers on the outer wall. Next to the main building one finds an auxiliary structure containing such services as toilets, wardrobes, etc. On the top floor of the main building there is a lunchroom along with everything needed to keep people occupied between working hours. And on top of that there is a wintergarden as well as a roofgarden. The various parts of the building are clearly expressed on the outside. Just as in Wright's houses, each part is separate from the others. Like two strong anchors the stairwells hold the core -- the stairs are lit by small skylights at a right angle with the flights, in order to avoid facing the light when mounting. [Wils, 1921, p 217.]

The major relationship of forms for ventilation and for the stair tower which served the interior at each of its five levels -- servant and served spaces -- was to have a profound influence on designs of the succeeding generations of architects in the Modern Movement. One of the most obvious and didactically important descendants of Wright's inventions was the Richards Memorial Laboratories (1961) on the University of Pennsylvania Campus, by Louis I. Kahn.

Wright's design for Unity Temple, constructed only two years after the Larkin Administration Building, bore the same marks of attention to services and their separation from occupied spaces as well as the relationship of structure to light and air, even though this was a building with much simpler environmental and at the same time more complex spiritual requirements (Fig. 5.32, 5.33). Square in plan, this building has four service towers, one at each corner. In describing his work on Unity Temple, Wright tells how each of the environmental conditions is met:

> The room itself -- size determined by comfortable seats with legroom for four hundred people -- was built with four interior free-standing posts to carry the overhead structure. These concrete posts were hollow and became ducts to insure economic and uniform distribution of heat. The large supporting posts were so set as to form alcoves on four sides of the room. I flooded these side alcoves with light from above to give a sense of a happy cloudless day into the room. And with this feeling for light, the center ceiling between the four great posts became skylight; daylight sifting through between the intersecting concrete beams, filtering through amber glass ceiling lights.
>
> Thus managed, the light would, rain or shine, have the warmth of sunlight. Artificial lighting shone from the same place there at night as well. This scheme of lighting was integral, gave diffusion and kept the room clear.

The combined engineering and poetic proficiency of Wright is nowhere shown to better advantage than in the Johnson Wax Administration Building in Racine, Wisconsin, begun the same year as the Fallingwater house and completed in 1939. According to Wright, the Johnson Wax Building, which he described as growing 'out of the earth and into the light,' was the direct descendant of the Larkin Building, designed thirty years earlier. The volumetric organisation of the two buildings differs markedly, however. In the Larkin Building, most of the clerical workers were placed along open balconies overlooking the central court where directors had their desks.

The Johnson Building is designed so that most of the clerical workers occupy the broad space of the great hall, surrounded by supervisors along the perimeter at both floor and mezzanine levels.

The main office space is a vast room with alignments of slender round piers tapering outward to support broad disc caps. Daylight filters through lozenges of green-tinged glass tubing between the discs, creating below the effect of being underwater in a lily pond. This generous space provides for staffing changes without architectural alterations. Therefore, through effective manipulation of structure and lighting details, Wright created an open space so complete that no one has felt it necessary to make major decorative changes over the lifetime of the building.

Wright describes his discovery of the opening up of the box at the angle between wall and ceiling in the Johnson Wax Building; he filled this angle with horizontal rows of glass tubing to give a feeling of space and light in a place where it might least be expected:

> Man could look out of the corner where he had never looked before . . . the life of the individual was broadened and enriched by the new concept of architecture, by light and freedom of space. [Wright, 1955, p 137.]

Through this tubing a liquid, partly diffused light floods the interior space, reinforcing the image of luminous space that is gently protected but not oppressively closed. Wright described the effect achieved here as one where 'weight . . . appears to float in light and air.' The clerestory formed by the tubing at the junction of wall and ceiling seems to negate the wall's structural significance.

Ten years later, Wright was called upon to build an adjoining research laboratory. He decided to avoid the usual dark experiment station depending entirely upon electricity for illumination, and conceived the new structure as a many-storied tower clothed in a glass garment. A central supporting shaft was left hollow for circulation and utilities, and the floors were alternately square and round. The glass dress was tubing identical to that used in the administration building. The research solarium was called the Helio Laboratory.

In the form of this tower and the shape of the Guggenheim Museum, we return to a Japanese analogy (Fig. 5.34). There is a similarity between the floors cantilevered from the central shaft of the Johnson tower and the mast construction which opened the floors up to the light, employed in Japanese pagodas. A comparison has been made to the 8th century East Pagoda of the Yakushiji at Nara, which has roofs and floor levels of interchanging projection depths (Fig. 5.35). The central posts in Japanese pagodas, however, did not support the structure.

Summary

Wright's interest in environmental tempering as a means of 'breaking the box' shows the power of climatic forces to give shape to architecture. The juxtaposition of the wall and ceiling planes of his spaces were in large part determined by the penetration of light and the flowing spatial effects that could be achieved. Form seems to be derived from the nature of the environmental force impinging upon it without taking precedence over it, so it cannot be clearly stated that there is a cause and effect relationship in Wright's environmental tempering. The derivation of Wright's spatial ordering and environmental techniques from such diverse sources as the medieval inglenook to the Japanese house and midwestern U.S. technology and craftsmanship shows his ability to forge strong linkages between environmental forces, culture, and the shape of spaces. The result is technologically innovative yet deeply rooted in the symbolism of the past.

6. Climate and Countermeasure in the Work of Le Corbusier

> The history of architecture is the history of the struggle for the window.
> --Le Corbusier

The question of the stylistic transmittal of ideas from one architect to another is an interesting one. If it happens it illustrates how the dissemination of 'morphemes' of environmental tempering -- the smallest meaningful morphological unit for controlling the environment, e.g. a window -- takes place across temporal and cultural boundaries. [Jencks, 1973, p 157.] It was unlikely that Le Corbusier could have been completely ignorant of Wright during the evolution of his own style, but it is difficult to follow the course of one person's style in the intricate tissue of European postwar architecture; Pevsner was of the opinion that 'the deeper the impression an architect of original genius receives from another of equal calibre, the less apparent will the links be.' [Pevsner, 1939] It is likely that the words and phrases for environmental tempering in Wright's architectural vocabulary found their way to Europe with the help of Dutch and German sympathisers. There they were taken over and used in new ways by other designers.

The Influence of Wright

There is specific evidence which points to Wrightian sources for Le Corbusier's early work and it is now thought that Wright may have had a major effect on Le Corbusier (Charles-Edouard Jeanneret) during the decade beginning 1910, contributing to several of the basic environmental principles of Le Corbusier's mature work. [Turner, 1983, p 350-359.]

The international spread and evolution of Wright's architectural forms began with the Wasmuth publications of 1910 and 1911; the countries which were the most affected were Holland, Belgium, and Germany. One of the most enthusiastic of European architects was H. Th. Wijdeveld -- who, incidentally, had seen illustrations of some houses by Wright in an American book as early as 1900, when he was only fifteen years old. He said afterwards, 'I could not sleep the first night I possessed the book; I was so thrilled.'

Wijdeveld staged exhibitions of Wright's work in Berlin, Cologne, Munich, and Antwerp. Neither London nor Paris were interested, coming perhaps from the strangely isolated development of the Modern Movement in France until after the war. France seemed at the time to be fulfulled by Garnier's Cite Industrielle of 1904 and Perret's achievements in ferro-concrete as models for innovation. These played the part assumed in Germany to a certain extent by Wright's forms and experiments. [Oud, 1925, p 85-89.]

Until 1983, the extensive literature on Le Corbusier contained only a few suggestions of Wright's influence. Reyner Banham spoke of Le Corbusier's 'ambivalent' attitude toward Wright, and mentioned the Wright-like plan and interior spaces of the Villa Schwob in La Chaux-de-Fonds, Switzerland, of 1916. [Banham, 1960, p 220.] Stanislaus von Moos and Maurice Besset later made similar observations, and Besset suggested more generally that Wright contributed to Le Corbusier's notion of the 'free plan.' [von Moos, 1968, p 52; Besset, 1958, p 27, 86.]

In recently discovered correspondence to Wijdeveld, Le Corbusier acknowledges his debt to Wright:

> It was around 1914 . . . that I first saw reproductions of Wright's houses and an office building . . . The sight of these several houses . . . strongly impressed me. I was totally unaware that there could be in America an architectural manifestation so purified and so innovative . . . Although I knew almost nothing about Wright, I still remember clearly the shock I felt at seeing these houses, spiritual and smiling -- with a Japanese smile . . . We are all too much in the habit of forgetting quickly those who have been directly helpful to our orientation. [letter from Le Corbusier to H. T. Wijdeveld, dated 5 August 1925.]

Among the first formal characteristics that appeared in Jeanneret's designs in a Wrightian context are the continuous band of windows extending along the full length of a facade and often even around the corners, the dynamic relationship of interior spaces of differing heights, and the plastic manipulation of architectural form by the removal of 'slices' from a building's mass in special ways.

One example of the transposed language is seen in the continuous row of small windows which first appears on Wright's Martin House, described by Berlage in his Schweizerische Bauzeitung article published in 1912 and almost certainly read by Le Corbusier. Banding fenestration appears shortly afterwards in Le Corbusier's architectural vocabulary in the Jeanneret House, La Chaux-de-Fonds (1912-1913). The idea of a horizontal row of windows, stretching the entire length of a facade and often even extending around corners, was repeated by Le Corbusier in other designs of the 1910s, such as a 'Dom-ino' house design that he later published in Vers une Architecture. Le Corbusier's caption to this illustration states that 'les fenetres font le tour de la maison.' [Le Corbusier, 1923, p 196.]

In the 1920s, Le Corbusier transformed this pattern of fenestration into a continuous window-strip, and it became an essential component of his mature work. In 1929, he listed it as one of his 'Five Points of a New Architecture,' the *fenêtre en longueur*. [Le Corbusier, 1965 p 128.] The Five Points were stated as, '*Les pilotis, les toits-jardins, le plan libre, la fenêtre en longueur, la façade libre*'. By then, Le Corbusier used the horizontal fenestration differently from Wright, emphasising the separation of the wall from the structural system, as seen in the Stein House of 1927.

The similarity of the Villa Schwob to Wright's plans has been reported by both Banham and von Moos. In the Villa Schwob, the Wrightian quality is also pronounced in the spatial character of the major rooms, with a double-storey living room open to single-storey rooms at the sides (Fig. 6.1). This interior spatial arrangement is expressed in the garden facade, which recalls Wright's designs for houses with two-storey interior spaces, such as the Roberts House and the Hardy House. This type of double-storey space onto which other spaces open from above or below became an important element in Le Corbusier's designs of the 1920s, such as the Citrohan House project and the *Esprit Nouveau* apartment prototype. Like the *fenêtre en longueur*, its development seems to have been inspired by Wright's published work. There were an additional array of features which were uniquely Le Corbusier's; among the elements which were specifically for environmental control were cavity walls housing services, and double glazing with heating between the panes, a precursor to his neutralising wall concept.

Just as Wright's distinctive patterns of fenestration evidently contributed to the development of Le Corbusier's mature work, so too did the play of mass and void in Wright's houses. Jeanneret's domestic schemes employing the Dom-ino system of reinforced concrete construction, are reminiscent of Wright's concrete Unity Temple (1904). Around this time Jeanneret's designs were characterised by an unusual feature: a recessed upper storey under a projecting roof aligned with the lower storey, giving the impression that a horizontal slice has been made into the cubic mass of the building, just below the roof. The structural columns passing through this slice are pulled back from the corners of the building so that the corners are completely open. This design feature recalls Wright's design for the Martin and the Coonley houses (Fig. 6.2). These effective but peculiar techniques of manipulating mass and void were among the most distinctive features of Wright's Prairie Houses. There is a 'breaking of the box' in Jeanneret's work of the 1910s (Fig. 6.3), which can be followed through a continuous progression to the free handling of facades in his work of the 1920s. This was an element that was eventually codified as another of his Five Points, the '*façade libre*.'

Thus Wright's works seem to have contributed to the evolution of several of the essential components of Le Corbusier's mature architecture. These include the horizontal window, the complex interior spaces that often have differing heights, the incorporation of foliage into his architecture, and the plastic manipulation of the mass of a building by removing corners and horizontal slices from it. To varying degrees, these features can be linked to four of the Five Points that Le Corbusier listed as characterising his work; the horizontal window, the free plan, the roof garden, and the free facade.

Le Corbusier submitted these elements of architectural language to radical transformation in his mature work and they eventually came to serve purposes very different from those of Wright. The connection between the two architects was further obscured by Wright himself, who in the 1920s encouraged the view that Le Corbusier's work had little in common with his own, attacking it as the essence of the worst tendencies in soulless and mechanistic modernism.

It is interesting that although Wright's influence was strongly felt in Europe, Le Corbusier by contrast had little effect on the direction of American architecture. It is possible to comprehend in part at least Le Corbusier's peculiar failure to be influential in the United States. He was designing houses for a class of people which -- with the exception of a few tiny enclaves here and there -- simply does not exist in America. Le Corbusier's schemes for single-family detached homes did not achieve wide acceptance. Wright, on the other hand was designing houses for members of the vast American middle class. This was a class to which he himself belonged for a good many years and whose needs he understood. Hence his houses of 1893-1913 are full of useful precedents which gave them popular appeal.

Environmental Tempering

From early in his career, Le Corbusier was aware of environmental problems and the human need to solve them. Much of his Manuel de l'Habitation refers directly to the need for environmental comfort and the ways of achieving it. His Unité de l'Habitation, which led to new trends in the construction of high-rise housing, is a study in the architectural control of environmental problems, from the brise soleil, the deep penetrating natural light, the cross-ventilation cooling, the thermal and acoustic damping to the provision of utilities and services. His proposals and executed designs were based on what he thought to be rational, scientific thinking. In his early work, however, the tempering of spaces fell short of their environmental promise.

His participation and contribution to the 4th C.I.A.M. La Charte D'Athènes of 1933 is well known and the recommendations or 'demands' of this charter were related to the provision of light, green space and air. The demands were based on proof provided by medicine, which 'has shown that tuberculosis starts where the sun does not reach.' This line of thought had arisen from Descartes carried on by his disciple, Fourier, eventually reaching the mainstream of architectural thought through the efforts of Jean Baptiste Godin, who felt that the three elements 'air, space, light' were embodied in human features. The Athens manifesto demanded that:

1. Zones of habitation be dictated by reasons of hygiene;

2. That the sun would penetrate into each dwelling a minimum of two hours each day, otherwise building permits should be refused;

3. That large buildings, separated by great distances from one another would liberate the land to large green spaces which would in turn re-vitalise the air.

The path of logic which delivered up the fenêtre en longueur as one of Le Corbusier's Five Points began with a rational search for truth -- 'Let us try and formulate some basic truths.' The deductive reasoning is worth including here as it goes forward, driven by the inexorable pursuit of space, air and light. The words and the emphasis are Le Corbusier's:

> The house is a shelter, an enclosed space, which affords protection against cold, heat and outside observation . . . The house is a question of materials. Its walls, floors and

roof are questions of suitability . . . what function is served by one or the other, what is its appropriate form, its size and its capacity for providing light.

The facade fulfils its true destiny; it is the provider of light. It can provide light with either 0 or 100 percent of its surface. The facade is enabled to supply 100 per cent light, because support is provided by the framework, of which the uprights are in the interior of the house and of which the crossbeams (borne by these uprights) terminate behind the surface of the facade and its windows (Fig. 6.4).

From this emerges the true definition of the house: stages of floors, light interior partitions varying on each floor and in strict conformity with the functions of the interior (the free plan): all round them walls of light.

Walls of light! Henceforth the idea of the window will be modified. till now, the function of the windows was to provide light and air and to be looked through. Of these classifed functions I should retain one only, that of being looked through. Air is provided by scientific methods of ventilation, which include heating in winter and coolness in summer. Light? glass in many different forms fulfils this function without having to reckon with windows (the most restricted organ of the house).

We have submitted to the laboratories of St. Gobain the basis of a new lighting substance which may have far-reaching consequences. To see out of doors, to lean out, that is henceforth all that the window need be used for. Is this necessary in every part of the house? No! And where the window is built into the luminous facade it will be as a definite organ, in the form of a complete mechanism. Plate glass replaces window panes. The sashes run horizontally, unhampered by the clumsy accessories of the sash window. They make possible the lengthwise window, the source of an architectural motive of great significance.

Aristotelian reasoning led Le Corbusier from solid walls to walls of light, to a definition of the one primary function of the window. A few years later he expanded the definition of the window back to its original three functions.

Le Corbusier's Language of Environmental Tempering

Le Corbusier, like many rationalist architects before him -- including Viollet-le Duc, August Choisy and August Perret -- conceived new languages stemming directly from changes in technology. Given a new awareness of the need for climatic tempering, and glass and concrete as materials to work with, a new syntax and semantic naturally followed. As Jencks has observed, Le Corbusier tried to create three new languages: a naturalistic, geometric Art Nouveau at age eighteen, Purism at thirty-one and Brutalism at fifty-nine. In each of them, the play of light and regulation of heat and air played a powerful role. He invented a repertoire of forms -- architectural signs -- which were semantically rich and based on function and technology. His stockpile of signs and words could handle functionally complex problems and were of such a universal and durable nature, that architectural movements in other countries developed from them.

In tackling environmental problems and solving them through the use of his personal architectural language, he would start with the rationalist method, as formulated by the 18th century French functionalist Abbe Laugier, from whom he often quoted.

> It is necessary to clearly state the problem . . . . If the problem is well stated, the solution will be indicated. [Le Corbusier, l'Art Decoratif d'Aujourd'hui, p 217.]

His definition of environmental problems started with the fundamental consideration of light and shadow. One of the many mysterious -- almost Freudian -- and amusing references to natural light in architecture is given by Le Corbusier in When the Cathedrals Were White, a Journey to the Country of Timid People, a book written about his first trip to the United States in 1935. He travelled to Vassar, a college for girls from well-to-do families, where he gave a talk, illustrated by drawings, to 600 girls. He speaks of Caravaggio, an Italian painter of the sixteenth century, who

> worked in a studio which was painted black; light came in only through a small overhead opening. Stop! Through him we discover a corner of the American soul . . . Caravaggio reveals under well-bred external appearances, a complex disturbance and the anxieties of sexual life. [Le Corbusier, 1947, p 145.]

In addition to letting in -- or keeping out -- light, there were other environmental forces which informed the creation of new words for his architectural vocabulary. One of the words, the '<u>ondulatoire</u>,' which he first used on the Secretariat at Chandigarh, restates the 'problem of the window' and defines it once more as having three, possibly more, separate functions: to ventilate, to view from, and to let in light. The three functions, which are somewhat compromised in the traditional sash window, are pulled apart and each is satisfied by a new form at Chandigarh. The various <u>brises soleil</u> shade the glass wall from the sun; vertical, pivoting ventilators of sheet metal allow fresh air in - otherwise ventilation is achieved by fans; finally the fixed glass wall, obscured at points for indirect light and open at other points for view, answers the two last 'problems of the window'. The system of <u>ondulatoires</u> became a new word in Le Corbusier's vocabulary to be used on the next building. This method of invention and subsequent purification and embellishment in his language accounts for the freshness and distinctiveness of all his work.

Also bringing a unique flavour to each of his works is the different way of emphasising the elemental forms through the use of colour and indentation in the design of loggia and <u>brise soleil</u>. For emphasis and to define its function as a 'parasol', the roof is sometimes lifted clear of the building. Each of the words is based on expressions of pre-existing elements; architectonic solutions to multiple functional problems. They can be co-opted and re-used by other designers more readily than a singly-determined form would be. He invented new usages and shapes and then found new functions for these shapes by moving them into new places. He transposed these elements enough to show that he was not a straightforward functionalist. [von Moos, 1971, pp 132-5]

The basic units of architectural meaning either invented or borrowed by Le Corbusier which have functioned for environmental control are: 1. the roof garden; 2. the free plan; 3. the ribbon window; 4. the free facade; 5. the loggia niche; 6. movable partitions; 7. the neutralizing wall; 8. the double height space; 9. the independent roof; 10. exhaust stacks; 11. ondulatoires; 12. brises-soleil; 13. cooling towers; 14. light catchers, and; 15. the three essential joys -- sun, space and greenery. [Jencks, 1973 p 190.]

This vocabulary of architectural forms reveals one of the fullest worlds a modern architect has developed, with meanings capable of encompassing the complexity of modern, urban life. Like the other 20th century heroic figures, Frank Lloyd Wright and Alvar Aalto, this broad morphological palette from which Le Corbusier borrowed freely, rests on a creative potency that seems almost superhuman, an act of man in complete domination of nature -- The Lord of All Creation.

In describing his struggle to develop the ideas for servicing and environmental tempering which one sees in his Radiant City and in the Unité d'Habitation, Le Corbusier writes:

> Look back. Think of Charles Fourier and his 'wild ideas' of houses supplied with communal services . . . 'water itself will be conducted through iron pipes into every house'. That was 1830 and Fourier was dismissed as a madman. So don't let's be afraid of ideas. [Serenyi, 196,p 22.]

In the Unité d'Habitation, public and private domains are turned inside-out and carried right through to the interior. The kitchen -- the place where the housewife conducts the family affairs with the aid of all her mechanical appliances -- is the centre of each apartment. The hearth, not the kitchen, had been the center of Wright's family life in the midwest American prairie. Le Corbusier underlined the role of the woman as custodian of the home by accentuating her place in the 'new hearth'. In fact, the exaggerated symbolic importance given to every element of family life was an old idea of Le Corbusier's, going back to the 1920s when he formulated the house itself as the central problem of contemporary architecture.He proposed that the major social disruptions caused by industrialisation -- uprootedness, chaos -- would be answered primarily by re-establishing the harmony of daily life and the home. [Jencks, 1973, p 18.] However, he made a clear distinction between functionalism and beauty in domestic architecture:

> The function of beauty is independent of the function of utility; they are two things. That which is displeasing to the mind is waste; because waste is stupid; it is for this reason that utility pleases us. But utility is not beauty. [Le Corbusier, 1929, p 44, 61.]

In addition to functionalism and beauty, Le Corbusier reveals his indebtedness to the authority of the vernacular sources in his derivation of the design for the Maison Citrohan and possibly subsequent apartment designs:

> We were eating in a little cabbie's restaurant in the middle of Paris [near the Madeleine]. There was a bar (zinc), the kitchen at the back, a garret-floor divides the height of the premises in two, the front opens directly on the street. Simplification of sources of illumination -- just one big bay at each end; two lateral bearing walls, a flat roof on top; a veritable box that could usefully become a house. [Le Corbusier, 1956 vol. 1, p. 31]

The design of the windows of Maison Citrohan depended on another vernacular source:

> We had observed that the glazing of factories in the Paris suburbs let light in and kept thieves out without any difficult joinery. And was very attractive aesthetically, judiciously used.

When travelling, he had the chance to examine airport design with a critical eye. On arriving at the Rome airport in transit on one of his many trips to India, he took note of the importance of solar control in glazed structures:

> very lively . . . and no control over the sun. The guy who meets me says it's very hard to live with. Always the same story, man and the sun. [Le Corbusier, Sketchbook no. 4, p. 835]

Whatever the sources of his inspiration, Le Corbusier continually nourished a passionate interest in the technology of materials and climate control. His sense of joy in the discovery of the principles of shade, light, air and greenery came to the surface when he was given opportunities to teach. Although he castigated the academic establishment, he enjoyed this brush with academe and took the opportunity to express his philosophy of education. In a lecture at the School of Exact Sciences in Buenos Aires, delivered in 1929, he told how he would go about teaching architecture. He would start with 'the facts':

> I would strive to inculcate in my pupils a keen sense of control, of unbiased judgement, and of the 'how' and 'why'. . . . I would encourage them to cultivate this sense till their dying day. But I would want them to base it on an objective series of facts. Facts are fluid and changeable, especially nowadays, so I would teach them to distrust formulae and would impress on them that everything is relative. [Le Corbusier, 1960 p 221-231.]

It is worth describing in more detail his method of teaching, and how he approached the step-by-step process of design for all architectural elements, including the window, for it gives an idea of what he felt to be most important:

> . . . How do you make a window? but incidentally, what is a window for? Do you really know why they make windows? If so, you will; be able to explain to me why a window is arched, square, or rectangular.
>
> Another point, just as important: Where do you make the window-openings? You realize that according to where the light comes from you get a particular feeling, so draw all the possible ways of arranging window-openings and then tell me which are the best.

He continues, explaining how he determined the proportions and the placement of windows at the Villa at Garches, using regulating lines. He started with a pure surface:

> I must enhance the flatness of this surface with a few projections or openings that will introduce an in-and-out motion, then locate the windows -- window openings play an essential role in our reading of architectural works. The placing of windows produces an impressive interplay of secondary surfaces, which introduces architectural rhythms, distances, intervals. What gives architectural . . . impact? The objects or surfaces you see, because they are <u>in the light.</u> The human animal is strongly affected by <u>sunlight:</u> this response is rooted in the inmost nature of the species. [Le Corbusier, 1960, p 221-231.]

So far it seems that the window is only a response to an artificial need for visual balance in the design of the facade -- an element of an artistic composition. But he is passionately convinced of the functional importance of the window, as well. He considered the importance of placing windows to be supreme; he diagrammed how the walls of the room are affected by the light (Fig. 6.5). His functional justification for windows is based on both poetry and a knowledge of human needs:

> This, in effect, is a crucial moment in architectural design, a source of decisive architectural impressions. You can easily see that style and decor no longer count. Think of those early spring days when the sky is full of wind-swept clouds; you are in your house; a cloud hides the

> sky: how sad you feel! The wind chases the cloud away; the sun comes through the window: how happy you feel! Other clouds plunge you back into shade: how eagerly you think of approaching summer, which will give you constant light! [Le Corbusier, 1960, p 74.]

He doesn't ignore the other building sciences in his lesson:

> Your studies are not yet finished. You will have to research into questions of sound, temperature, and expansion. Of heating and refrigeration. The more direct experience you can pick up at this stage, the more thankful you will be later on. [Le Corbusier, 1960, p 232.]

In a more formal way, he lectures on the history of the horizontal window as one of his Five Points Towards a New Architecture:

> Together with the intermediate ceilings the supports form rectangular openings in the facade through which light and air enter copiously. The window extends from support to support and thus becomes a horizontal window. Stilted vertical windows consequently disappear, as do unpleasant mullions. In this way, rooms are equably lit from wall to wall. Experiments have shown that a room thus lit has an eight times stronger illumination than the same room lit by vertical windows with the same window area.
>
> The whole history of architecture revolves exclusively around the wall apertures. Through use of the horizontal window, reinforced concrete suddenly provides the possibility of maximum illumination. [Le Corbusier, 1926.]

Le Corbusier's poetic imagery on the subject of light, shade and architectural form appears repeatedly in his sketchbooks over the years. These passages, quoted verbatim here, continually make reference to the elements of nature; sun, wind, light, hot, cold. The context is always important, and is signified by the mention of specific buildings or places:

> wood lattice enclosure wall very big trees//rue de Longchamps W[est]//very noisy//close off on this side//Rather dark hole//S[outh]//N[orth]//we have the right to make a wall here//design an enclosure [wall].//east the neighbor//party wall//kitchens//2.50 m. for blind walls//9 m. for window walls
>
> no. 550

Jaoul // Neuilly // summer '51 south party wall // noon
attention winter sun

no. 549

for the High Court in the niches also find modern symbols 24 hours//the 2 solstices front view//full planes//profile//direction of solar rays

no. 769

I saw this morning a tomb near the IInd Pyramid, where there was a little queen on square pillars, in raking light, alive and feeling.

no. 783

urgent Maissonier. No ceiling lighting that would make a hole. But the seam [between] ceiling // [and] wall.

no. 101

Sun control. Assembly 1 pm on the roof heat enough to kill burning sun. I step inside the stairway exit lobby = open, but covered. Great coolness. The sun has not heated [it] up. Moreover, the draft comes from below = 2 things a/ the air temperature of the enclosed shadow//b. the air friction = evaporation // outside // inside // amazing contrast . . . sun control remarkable in High Court 2

April 1962

Nov 1955 Tokyo the gleam of lights ... winter wind dry and cold to be avoided // summer wind South N[orth] cool but humid very useful = make air currents

Sketchbook 3

Chandigarh -- in the cone = direct daylight through telescopic tubes. Open hand sculpture -- arrange for it to turn by means of ailerons.

Sketchbook 3

west / winter // Longchamp // pilotis plan for an enclosure wall here in the east = shaded in the morning light reflecting in the afternoon

no. 553

The mathematical phrase: 'that which makes wrong difficult and right easy' Marseille is the hymn to the Modulor as it approaches completion. everything moves in immense music

no. 566

invincibly towards the south//towards the sun//relentlessly since the age of 19 until today 72 years old.

Sketchbook 4

As Wright did before him, Le Corbusier used architectural elements in new functional contexts. This permissiveness in design method has led to the conclusion of Philip Johnson and others that 'form follows previous form, not function'. In fact the relation between form and function is more complex than either the formalists or the functionalists have explained it. In Le Corbusier's work there seems to be a cybernetic relationship between the two aspects, that is, a system of control and communication such that form and function continually interact in a dialectical way.

To demonstrate this interaction, examples of functionally based elements such as the inglenook or the window can be cited. If the fireplace is transposed from one culture to another or from one era to another, it takes on new symbolic functions. A fireplace becomes more than a source for heating in the domestic architecture of the 20th century. Similarly, windows were used in new ways by both Wright and Le Corbusier -- as a band which at the larger, exterior scale slices pure, flat shapes and at the interior scale opens the room up to light. A window is more than a window. Jencks uses the allegory of the toilet as an example *reductio ad absurdem*. In cultures where it has been recently introduced, the porcelain toilet is used for other purposes, i.e., for washing grapes. Given time and semantic explanations in these 'primitive' cultures, the toilet would finally come to be used as intended, until it could achieve, as in our own culture, its final culmination as a beautiful object in art history. Its sculptural properties could be explored only after its functional abilities had been fully realised. Still, in spite of these extensions in its use, this white, enamelled object has a definite, partly fixed meaning which was determined by its initial function.

Domestic Architecture

The path of evolution for the environmentally-tempered house-as-a-machine-in-which-to-live was littered with lessons learned from experimental structures for Le Corbusier's immediate family. Among these was a small summer house on a lake in Switzerland for his parents. A simple dwelling, it nevertheless was important to Le Corbusier in determining the climatic context for a house and in fixing the relationships of architectural elements, such as the proportions and position of the window on the wall. Le Corbusier's account of this design is told in a didactic, partly allegorical story, called 'The Little House.' It is reproduced here partly because it is not widely available and it is important in establishing how he approached the problem of relating a simple building -- starting at the beginning -- to the site and the climate. As in Vitruvius, architectural analysis begins with the definition of a healthy site:

The Little House

> The main points of the plan. First: the sun is to the south -- that's something! The Lake spreads out to the south, backed by the hills. The Lake and the Alps mirrored in it are in front, lording it from east to west. That is some sort of setting for my plan: facing south, its length is a living room four metres in depth, but sixteen metres long. The window, by the way, is eleven metres long (one window, mind you!).
>
> 'Four metres away from the lake!' said people; 'you are crazy! You will have rheumatism and the glare from the lake will be intolerable.'
>
> 'People' don't observe or think. When a kettle boils over, where is the steam? Above the kettle, but not beside it. Rheumatism from damp . . . attacks those living on the hills at an altitude of fifty to one hundred metres. The damp is above the kettle!

And the glare from the lake? The sun passes in front of us from east to west and reaches its zenith only at the summer solstice. The angle of incidence will never pass through the little house. It reaches -- and dazzles -- those living on the hills at an altitude of fifty to a hundred metres.

'People' know nothing of the angle of incidence.

The walls were built of hollow blocks of cement concrete and sand -- good conductors of heat and cold, and hence poor material.

. . . At the furthest extremity there is a genuine architectural element -- with apologies to Vignole!: . . . three small horizontal grille windows which give light to the cellar. That is enough to make for happiness -- if you don't agree, please pass on!

The reinforced concrete forms the terrace roof and, with twenty or thirty centimetres of earth, the 'roof garden'. . . each tiny leaf gives shade and the compact roots insulate from heat and cold. They regulate the temperature without costing anything or requiring any upkeep.

Pay attention! It is towards the end of September. The autumn flowers are blossoming and the roof is green once more, for a thick carpet of wild geraniums has overgrown everything. It is a wonderful sight. In spring the young grass sprouts up with its wild flowers; in summer it is high and luxuriant. The roof garden lives independently, tended by the sun, the rain, the winds and the birds which bring the seeds.

Latest news. April 1954; the roof is completely blue with forget-me-nots. No one knows how they arrived.[Le Corbusier, A Little House (n.d.) Fondation Le Corbusier, Paris, p 5-45]

The La Roche - Jeanneret house was one of Le Corbusier's first formal experiments in bringing to life his Five Points. Lotti Jeanneret wanted a family house with light, air, and modern facilities. Family life in the Jeanneret House, like the branches of a tree, gravitated toward the upper part of the house into the sunlight and fresh air. There was a progression from the enclosed, compartmentalised spaces of garages and rooms for maids and caretakers, through bedroom and living room floors, finally culminating in the sunlight and a roof garden. All of this was in accord with Le Corbusier's growing devotion to the lessons and solutions which nature offered the architect.

Technical difficulties and inconveniences were endured by Le Corbusier's friend and client, LaRoche, whose letters to Jeanneret have been saved. One of the problems was with the electric lighting. On 18 October 1925, he wrote:

> I understand perfectly your hesitations about the way you want eventually to provide lighting in my rooms. But until you have found a very good solution, it is essential that at least I see clearly in my house. For more than six months when I come in I am obliged, especially in my painting gallery, to have makeshift lighting. What must the many visitors think about it and what would you have me say to them? [Walden, 1977]

In the Ozenfant house, Le Corbusier's fenestration pattern is developed by unrolling the continuous envelope of the house onto the plane of the drafting paper. If the two facades of the house are projected onto one plane, their symmetry is instantly apparent. The initial contrast of four and three windows in the Jeanneret and the La Roche bays respectively is later refined to a permutation of their differing number of narrow and wide windows, three narrow units framing two wide ones in the extruded bay as against three wide ones enclosing two narrow units in the set-back portion (Fig. 6.6). [Walden, p 323.]

In the Villa Savoie the first floor, surrounded entirely by a ribbon window, consists of the complete living accommodation wrapped in an L on one side of the open terrace. Light and air penetrate everywhere. Direct contact with the surrounding landscape is achieved by various openings, views are framed like a picture. In 1930, Le Corbusier interpreted his own Villa Savoie with respect to its ribbon window:

> The house is a raised box segmented by a continuous strip window . . . [which] provides views and sunlight for all the rooms. These surround a terrace garden, which provides and controls the sunlight. The sliding glass walls of the drawing room and several other rooms open freely onto this terrace garden: the sun thus comes in everywhere, penetrating the very center of the house . . . look at the section: air circulates everywhere; light reaches every point, penetrating everywhere (Fig. 6.7). [Le Corbusier, 1960 p 74.]

Verdure spills out of boxes on the terrace and solarium. Jencks has likened the feeling to that of being at a 'heroic health camp'. The bathroom, with its tiled sunken bath and <u>chaise longue</u> of tiles might have been found in a Roman bath. It was the first point of <u>The Manual of the Dwelling</u>:

> Demand a bathroom looking south, one of the largest rooms in the house or the flat, the old drawing room for instance. One wall to be entirely glazed, opening if possible onto a balcony for sun baths; the most up-to-date fittings with a shower bath and gymnastic appliances. [Le Corbusier, 1927, p. 114]

<u>Brise-soleil</u>

In 1947, Le Corbusier traced the history of his investigation of ways to control the effect of sun on buildings. It is a good example of the way he studied a problem over extended periods of time, pulling the solutions fom his 'bag of tricks' years later when the situation called for it:

> After twenty-five years of study a new element may perhaps be definitively incorporated into the architecturew of steel, concrete, and glass. '<u>Brise-soleil</u>' introduces a new technique: sun control.
>
> Steel and reinforced concrete . . . led to the open plan; the open plan led to the nonbearing facade; the nonbearing facade led to the glass skin. It was a natural, inevitable evolution. . . . The use of the glass skin -- there is no progress without experimentation -- revealed . . . disadvantages.
> One day, while I was considering Mediterranean problems ... the solution came to me: install, in front of the glass

> skin, a device regulated by the sun's daily path as it varies between the solstices and equinoxes. The brise-soleil, as an architectural event, was born.
>
> This was in Rio de Janeiro in 1936. While working on the plans of the Ministry of National Education and Public Health with Luccio Costa . . . I answered an anguished question: Don't worry, we'll use brise-soleil.
>
> The right solution had been staring me in the face for years. During my travels I had often seen, in luxurious as well as indigenous forms of architecture, that admirable architectural organ, the loggia. [Le Corbusier, 1948, p 48.]

Larger Buildings

The opportunity for the use of monumental forms based on environmental tempering was offered to Le Corbusier in commissions for the design of larger buildings. The brief for the Centrosoyus Office Building, Moscow (1929-33), gave important reasons for developing climate-control using advanced techniques; the client 'wished that the building should express the latest resources of modern technology.' [Winter, p 329.] Le Corbusier's response was to give it a steel and glass curtain wall erected from the top down. This obviously presented an environmental challenge in the harsh winter climate of Moscow (Fig. 6.8). Mechanical ventilation was designed to give comfort to the occupants in such a glassy building, but the Russian authorities -- with foresight -- would not agree to the application of Le Corbusier's un-proved principle of 'respiration exacte.' It was therefore built with opening windows for ventilation in summer -- no air-conditioning -- and radiators for heat in the winter. The radiators proved adequate in winter but the large expanses of glass -- even though openable -- made the building too hot in summer. The answer, Le Corbusier stated later, would have been to add brise soleil. [Winter, p 323.]

The Immeuble Clarte at Geneva was a block of forty-nine flats, built for the client, who was also a builder and adviser, Edmond Wanner. Le Corbusier absorbed a great deal of technical know-how from this man. The apartment has a testimonial to this time of learning in the form of a remarkable staircase that allows light to filter down through eight floors of glass treads. This staircase seems to be a descendant of a similar design sponsored by the Luxfer Light Prism Company at the Werkbund Pavilion (Fig. 6.9).

The Clarte apartment building also breaks new ground in construction technology. Reinforced-concrete piles support a steel frame with all joints electrically welded -- perhaps one of the first anywhere -- and frames for the double-glazed windows are welded to the structural frame of the building. As for environmental tempering, it was never intended to have mechanical ventilation, so blinds and balconies are wisely provided to protect the glass area from the summer sun; perhaps a pragmatic suggestion of Mr Wanner.

The Pavilion Suisse, Paris (1930-1932), provided the testing ground for Le Corbusier's 'pan de verre en facade sud.' The concept was more formal in its expression than functional. It did not show a scientific understanding of the problem of solar heat gain nor the tremendous, unabated glare of light which came from the bright southern sky. The solution to these problems had to wait another five years until he had invented the brise soleil to cope with the sun. In the Pavilion Suisse itself the occupants managed for thirty years until the owners of the building provided external venetian blinds -- a form of brise soleil. [Winter, p 323.]

The Pavilion Suisse was described as the first academic building of the modern movement and as such it had a tremendous influence on contemporary architecture worldwide. This design might be parallel with Alberti's schema in another technology: platform, walls, apertures and covering. In this building, the plastic system is complete. According to Le Corbusier, it contained all the elements, independent one from the other:

> le plan libre, les poteaux, les gaines, les parois courbes, l'escalier, sont autant d'organes independants, les uns des autres. [Voelcker, 1957, p 43.]

Each environmental and structural function was isolated and resolved in built elements in a self-assured way; '*Pilotis*,' glass screen to the south, opaque panelling to the north, and *'la toiture'* clearly stated in concrete, glass, facing slabs, and paving. Only the most tenuous joints born of necessity link the elements together. The steel frame is implicit in the cellular form rising from the slab held over the pilotis.

The failure in environmental tempering of the *Cite de Refuge*, Paris has been well documented by Banham and others. The curtain wall was elegantly detailed, designed for the passage of air at a controlled temperature to pass between the skins. This was the *mur neutralisant* concept which the Russians had refused to endorse, developed in conjunction with the St. Gobain glass company, but with an astonishingly tenuous scientific foundation. He was evidently quite proud, however, when he said about the Cite de Refuge:

> It is the first entirely hermetically sealed dwelling structure, comprising in particular a thousand square meters of glass with no openings. [Le Corbusier, 1956]

The disastrous shortcoming of the theory of the *mur neutralisant* method of maintaining internal temperature by passing heated or cooled air between two skins of glass was in the fact that it allowed radiant heat to pass through and to cause overheating in summer. But the real disasters at the _Cite de Refuge_ were not in theory but in practice, for neither the inner glass skin nor the cooling system were installed, while the skin itself was sealed tight. When wartime damage, neglect, and the action of rust on the window frames caused glass to break, the owners patched the windows with solid panels and concrete blocks. Then in the early fifties opening windows were provided for ventilation, spandrels were used to reduce the glass area, and ironically, Le Corbusier's invention, _brise soleil_, were added to cut down the sun's heat.

The U.N.E.S.C.O. Headquarters Building in Paris was a design strongly influenced by Le Corbusier, although he had been dealt out of the commission by being made a member of the design committee, along with Walter Gropius. In a lecture at the Sorbonne, he bitterly recounted his experience. He accused the committee of perverting his intention, which was to design a building using a biological metaphor with clear environmental definition:

> . . . an efficient tool, a perfect biology, an impeccable symphony of form, organised cosmically in accordance with the sun. . . [Equipped] with sun control by means of _brise soleil_ to create a dazzling shell . . . a great concrete greenhouse; in fact it's a harmonious organism exposed to all the sun's favourable angles.

By the time of his commissions in India, Le Corbusier was apparently in complete, self-assured command of the idiom of sun protection and light control. The Nine High Courts of Justice at Chandigarh (1956), are protected from the radiant pressure of the sun by rhythmical _brises soleil_ and a gigantic parasol, raised above the roof, which keeps out the sun and rain and allows air to circulate over the courts. However, they too have suffered a series of alterations due to a lack of functional foresight. Reportedly, a concrete sunshade had to be added at ground level because the courts were overheating. The opportunity was taken by the eminent judges to switch the operation of the courts around, placing themselves against the brilliant light of the windows. This eliminated any difficulty in seeing the faces of the accused against the glare of the windows, the better to tell if they were lying. [Jencks, 1973. p. 156.]

The Venice Hospital scheme (1965), designed late in Le Corbusier's life, is an exercise in pure Parthenon austerity, perhaps more appropriate to other building types. It is the ultimate in efficient planning, with the all-important element of natural lighting shown clearly in the section (Fig. 6.10). It was never built, and it has been criticised as being 'morgue-like' and not offering patients the human qualities of warmth and variety in spatial experience. [Jencks, 1973, p 163.] It does, however have some interesting environmental characteristics. The daylighting provided by a clerestory seems to be an early form of what later came to be known as a 'light shelf' -- in the parlance of energy-conscious design of the 1970s. It introduces indirect daylighting into the space, avoiding problems of glare -- whilst at the same time denying direct visual contact with the outside. The design was evidently intentional, for in Le Corbusier's words:

> The form of the patients' rooms represents an entirely new solution: each patient receives an individual cell with no windows to look out of . . . Daylighting remains well distributed as does the room temperature so that the patient can enjoy calm isolation. [Le Corbusier 1967, p 176.]

As in his design for La Tourette, where he returned to a sort of austerity which is becoming to his aesthetic, there is an intentional absence of warmth and humanity; in La Tourette, there were long empty, corridors, almost visceral in their symbolism, containing just radiators, doors and brightly painted water pipes. This arrangement has the ability to be at the same time both dull and extraordinarily dramatic. According to one visitor, the Dominican monks

> . . . take the visitor through these corridors, pointing out the changes in light, the sudden glimpses of nature and the way all the forms move in relationship as one walks. The interior of the church, which to a layman might be a shoddily constructed, blank box, is to the monks and Le Corbusier the essence of 'ineffable space', light, calm, proportion and stark forms in tight relation. [Jencks, 1973b, p 172.]

Beyond the monumental scale of the large building, he devised many schemes at the urban scale which attempted to deliver light air and greenspace to the oppressed city-dweller (Fig. 6.11). His entry into the field of urban planning came in the early 1920s. He defined the goal of the Radiant City as follows:

> The radiant city, inspired by physical and human laws,
> proposes to bring machine age man
> essential pleasures . . .
>
> Sun in the house
> a view of the sky through large windows
> trees he
> can see from his house.
>
> The materials of urban design are:
>
> sun
> sky
> trees
> steel
> cement
>
> in this order of importance.
>
> [Le Corbusier, 1964 p 85.]

<u>Summary</u>

More than any other architect, Le Corbusier was able to impart universal lyrical and dramatic meaning to sun protection and light control through the development of a series of environmentally related morphemes. His climatically responsive facades became a 'look' which was internationally successful, but nowhere better integrated with architectural intention than in his own works.

His attitude toward science and art was at times contradictory. He insisted on the importance of scientifically informed design, however his conclusions often misfired initially. The bold use of architectural invention expressed a new shape of environmental tempering which combined classical purity with the technology of the 20th century.

7. Alvar Aalto: Climate and Metaphor

> The norms should not only require that each dwelling get sun; the angle of incidence should also be decided, to, let us say, one degree's leeway.
>
> Aalto, 1978.

Alvar Aalto was self-assured in his ability to combine romance with technology in buildings that are pragmatic yet intensely personal. His achievements include the seminal Paimio Sanatorium (1929-33), in which he sought environmental perfection by using materials and arranging spaces in such a way as to give height, openness, light and air along with the well-designed provision of services. Throughout, his designs show an understanding of environmental management, including the manipulation and control of light, heat and sound.

Aalto was not given to writing nor to the comprehensive development of a theory describing his design method. The written record of his thought is relatively small when compared to that of Wright, Le Corbusier and Kahn. However, the attitudes he held towards art, technology and architectural problem-solving were widely reported. He makes continual reference to nature in both his recorded statements and in his designs. He was interested in the way that his architectural concepts evolved and he illuminated this process by poetic allegories such as the following one which appeared in 1947:

> . . . architecture and its details are connected in a way with biology. They are perhaps like large salmon or trout. They are not born mature, they are not even born in the sea or a body of water where they will normally live. They are born many hundreds of miles from their proper living environment. Where rivers are but streams, small shining

bodies of water between the mountains, under the glaciers' first melting water drops, there they are born, as far from their normal environment as man's spiritual life and instincts are from his daily work. [Aalto, 1978, p 97-98.]

Aalto's approach to technological expression and refinement is based on a deep regard for biological prototypes. He believed that the best examples of architectural standardisation were contained in natural, living systems, an idea which revealed the influence of Oriental thinking and which paralleled some of the ideas of Wright. His architectural aesthetic owed its origin more to nature than to pure technology which had 'found its way into architecture'. He strongly held that architectural problems cannot generally be solved by technical means. His architecture avails of technology, but the way it does so is to aim at harmonising technical and natural characteristics. He called architecture a 'supra-technical' form of creation based on the harmonisation of innumerable functional forms:

A building is in no wise a technical problem -- it is an 'arch-technical' problem. Technical design methods cannot therefore be adapted to suit it. The standardisation in this instance should be arch-technical. [Aalto, 1978, p 32.]

He cited examples from the past where architecture was treated as a sort of technical specialisation. These attempts to apply technology to architecture resulted in failures which had 'grave social repercussions:' His favourite example was Thomas Alva Edison who spent years attempting to solve an architectural problem -- the standard house -- using technical methods. This led Edison after years of effort to the only real defeat he experienced in his lifetime.

His designs were based on an awareness of the relationship of shelter and human activities to the surrounding elements. This concern surfaced in his dedication to solving a range of environmental issues, from lighting, heating, ventilation and air pollution to acoustics. As early as 1930, he discussed the meaning of 'air quality' in relation to ventilation:

> The biological conditions for human life are, among others, air, light, and sun. Air does not have to do with the size of the rooms or their number. It is an independent concept. We can surely build a dwelling with a large cubic footage of air without using the floor area uneconomically and affecting the ceiling height. The air space is a question of ventilation. On the other hand one must give a great deal of consideration to the air's quality. And this is a question that is dependent on the city's internal organisation, the town plan. [Aalto, 1978, p 32.]

His interest and expertise in town planning is less well known than his architectural work, however it is relevant here because it reveals his insight into problems resulting from the rapid assimilation of technology in the form of the automobile, and illustrates his concern about the impact of technology on environmental quality. Indirectly, he commented about man's relationship to technology in the Annual R.I.B A. Discourse in 1957. The mood is one of nostalgia for time lost, when things were simpler and the relationship of man to nature was more direct. In a way, it is reminiscent of Seneca, when he longed for less dependence on technology:

> Our streets and cities were designed for completely different purposes -- as was the nice Boulevard Italien, for horse traffic, a few horses here and there. Now it's full of automobiles -- and we know they are . . . putting out a very dangerous heavy gas which lies on the streets . . . today we are paying a very high price for our inability to build a new traffic system in which pedestrians and automobiles are far away from one another, not to speak of housing and living. [R.I.B.A. Annual Discourse, 1957.]

He didn't lose sight of the many technical and human issues in architectural design, and the nature of solving the complex problems often arising from contradictory requirements. He described these difficulties and their solution in his own professional practice. When he had to resolve an architectural problem, he was invariably overcome by the thought of its realisation. He said that what he needed was a sort of '3 a.m. courage,' due to the weighty importance and difficulties in resolving the different elements at the time of conception. He included among these elements the social, human, technical and economic requirements side by side with the psychological factors and a concern for each individual and each group, their rhythm and internal friction. These elements became so numerous that they formed 'an entanglement,' not lending itself to methods of rational resolution. The resultant complexity initially prevented the basic architectural idea from taking shape. [Aalto, 1957 p 138-139.]

Aalto called on the help of poetry -- an expression from Strindberg -- to describe his feeling for irreconcilable contrasts:

> Goldpower at the ironspring
> Coppersnake under silver linden
> that is the lady of the wood's riddle
> that is yours and mine.

He interpreted this poem by Strindberg to mean that apparently irreconcilable opposites may at last in one way or another be brought into harmony. He felt that Strindberg's way of placing the opposites next to each other hinted at the manner in which art and the purely material world could be united.

Under these circumstances, he claimed to work in a completely irrational way. His technique was to forget the whole entanglement of problems, clear it from his head and occupy himself with painting abstract art. When he resumed designing, he allowed himself to be guided purely by instinct -- and, suddenly, the basic concept would appear and the different, often contradictory, elements would be put in harmony.

He gave an example of irreconcilable differences in environmental tempering being harmonised in the design of his churches. The nature of the geographical and local siting, the building materials for the walls, roof, heating system, ventilation, lighting, and surface treatment he considered to be basically independent of each other. In addition to being independent considerations, they are also often in conflict with one another, and yet it is necessary to bring them into harmony. According to Aalto, only if and when this harmony is achieved does the building become a 'cultural factory' of permanent value.

In the Imatra Church, for instance, one is initially greeted with a cold, white, Protestant light; pure, clear rational confirmation of the presence of religion without belief. The resolution of conflicting environmental variables occurs at the junction of roof and wall. The acoustic curve of the ceiling signals the undulatory nature of the roof, pinched together at the juncture of windows, sliding door and ventilation equipment (Fig. 7.1).

As with the design of a church, he felt that nearly every design task involved thousands of different antagonistic elements, which can be forced into a functional harmony only by man's will. This harmony for Aalto could not be achieved by other than artistic means. The individual technical and mechanical elements received their definite value only by artistic will. He felt strongly that a harmonious result could not be achieved via calculations, or with the help of statistical data or probability studies:

> There are statistically based methods and some kind of Gallup system with whose help it has been attempted to achieve a harmonious whole. There is, for example, an enormous hospital, recently built, based on the movement patterns of the staff, in the hopes of simplifying the

> biodynamic movements of the people working in the building. The results have shown themselves to be totally unsuccessful. It was an attempt to achieve a total solution relying on a subordinate factor. [Aalto, 1978, p 40.]

Aalto once heard a student present a thesis concerning a children's hospital. The student had attempted to find the overall solution not only through one secondary method but through many. The analysis of movement patterns took half an hour of the speaker's time. There were the space needs for children of different ages, different light angles in the window systems, easy maintenance of surfaces, etc. Aalto considered all of these to be good things in themselves if one understands them as subordinate elements, but they were in this case not sufficient to create a humane environment or a functioning whole. When the student had finished counting up all these methods and presented his technical solutions for all the cases, Aalto said:

> You have apparently still left out at least one possibility. How would the building and the sick children in it function if a wild lion jumped in through one of the windows? Would the dimensions be suitable in such a case? [Aalto, 1978, p 127-128.]

The answer was a deep silence in the whole auditorium. Only the laugh of an experienced pediatrics professor from Harvard could be heard.

His interest in the metaphorical power of biology and nature ultimately referred to the form-giving quality of sunlight and its central relationship to the shaping of his architecture. This dedication to the strength of forms derived from solar geometry was pursued with precision and attention to detail:

> Light and sun. Under extreme conditions one can no longer leave the dwelling's access to the sun to chance. Light and air are such important preconditions for living that the haphazard conditions that prevail today must be changed.

> sun; the angle of incidence should also be decided, to, let us say, one degree's leeway.
>
> The sun is a source of energy; but only if we use it in a scientific way and in exact quantities will it become, under all circumnstances, a positive factor for the biodynamic concept that involves the family's and the single individual's life within the dwelling's walls. In a fifty-square meter dwelling we don't have, in this regard, the slightest margin to be left to chance, nor can we afford to allow the sun's and the light's energy to remain unused. [Aalto, 1978, p 32.]

His interest in the sun extended to the potential of solar energy for heating. His studio at the experimental house at Muuratsalo 'crowned' the entire group of buildings. It was not connected to the heating system of the other buildings. It was a separate pavilion which was an experiment with solar heating such that wall and roof surfaces, which accumulated solar heat, were independent of the building's other parts. The whole complex of buildings at Muuratsalo is dominated by the fire that burns at the center of the patio and which, from the point of view of practicality and comfort, serves the same purpose as a campfire in a winter camp. The glow from the fire and its reflections from the surrounding snowbanks created for Aalto a pleasant, almost mystical feeling of warmth.[Aalto, 1978, p 116.]

Although he claimed not to have a feeling for folklore -- that the traditions that bound him lay more in the climate -- Aalto acknowledged the spatial genealogy of his own designs by tracing their origin to the single, stove-heated room in a Finnish vernacular house:

> Most people look at the room as a standard measure for the dwelling. In big dwellings there are many rooms and a kitchen. If we descend the ladder we finally arrive at the classical Helsinki miniature dwelling, 'room with stove.' [Aalto, 1978, p 33.]

His designs owed allegiance to both Nordic and Mediterranean precepts; two regions remote from each other geographically and dissimilar in climate, but linked by migratory patterns. There is also a relationship of Aalto's work to contemporary architectural activity in Central Europe, where people live between the two regions and experience the difference between them, whereas in northern countries people are far from the Mediterranean region and traditionally yearn for sunshine. This is a fundamental feeling and yearning that finds expression in Aalto's architecture. The expansive, unarticulated facades found in many of his constructions are oriented so as to catch the reflections as well as to re-direct horizontal rays from the cold northern sun and thus to create the illusion of a more intense light than really exists.

On the other hand, the semi-open and closed atria which are so typical of the Mediterranean area are often used in the north, too. However, their purpose there is not to offer shade as in the south, but to collect light and to provide enclosure and protection against cold winds. In using these form-giving elements, Aalto's architecture shows a transformation of features typical of the Mediterranean region, whose architectural tradition he admired. It is fitting that his final building -- a church which was constructed posthumously in Italy -- is physically located near the Mediterranean but is conceptually bound to his ecclesiastical forms of the North.

His work is characterised by attention to details of comfort and climate and a virtuosity of finish which was alien to his predecessors, Haering and Scharoun. The comparison of his work to theirs can be likened to the difference between <u>anima</u> and <u>animus.</u> [Slapetka, 1980, p 115.] When Aalto's works are compared with Scharoun's it seems that the difference between them is similar to the difference between male and female. Scharoun seems to be more forceful, careless, masculine and virile, often deliberately anti-aesthetic and uncomfortable, whereas Aalto always strives for a perfect aesthetic impression. Aalto pays attention to the delicate contextual placement of his buildings in their environment, and they exhibit a womanlike beauty and perfection of contour, with refinement and elegance in every detail, including their relationship to the harsh exterior climate. From a formal point of view, Aalto, unlike Haering and Scharoun, did not abandon the rectangular basis of his compositions, which are shaped like Japanese fans or classical Greek theatre plans. Free shapes appear only in some dominant functional aspects.

Aalto did not become aware of Wright's work until a trip to the U.S. in 1939, when he saw his buildings for the first time. The Bauhaus did not interest Aalto as much as the Jugend Styl with its contintental origins, especially the work of Henri van de Velde. His reaction to Le Corbusier was that he was an architect who had for the most part expressed himself by writing books:

> . . . and with books it is as I once said in a conversation with General Talvela. He told me he doesn't read books about war, but rather about art and architecture. I confessed that I gladly read books about war but never about architecture. [Aalto, 1978, p 171.]

Aalto was cynically aware that objects which were labelled 'rational' often suffered from a noticeable lack of human qualities. Disregarding for a moment the possibility that the missing elements could be introduced merely by adding 'more form', he felt that if a closer study were made of the 'facts', the rationality of a designed object most often applies to a few of its characteristics but not to all. Aalto thought that the origins of rational architecture were in some way connected with the method of production. He used the tubular metal chair of Marcel Breuer as an example:

> To achieve a springy seat merely with a few bent tubes and some tightly stretched bits of leather is in itself a clever technical solution. It can in this regard justly be labeled rational. It can also be considered so in many other respects, primarily from a structural viewpoint. [Aalto, 1978, p 48.]

But he felt a chair has an endless series of requirements that it should fulfil and not til it fulfils all of them in a reasonable way -- even though different requirements come into conflict with each other -- can it be regarded as a thoroughly rational creation. The point to be made is that the main criterion of rationalism for Aalto was in fulfilling all the definable rational requirements so that they form a totality without conflict. He imbued the chair with criteria for thermal and visual comfort, and in so doing, arrives at a scientific definition of 'cozy':

> If we wish to list the requirements that these chairs do not succeed in filling we could mention the following: a piece of furniture that forms a part of a person's daily habitat should not cause excessive glare from light reflection; ditto, it should not be disadvantageous in terms of sound, sound absorption, etc. A piece that comes into the most intimate contact with man, as a chair does, shouldn't be constructed of materials that are excessively good conductors of heat. I merely name these three criteria that the tubular metal chairs hardly fulfill. One could list a large number of additional requirements that in this particular case are not met.
>
> The main criticism against the metal chairs has been that they are not what one would call 'cozy.' this has in most cases been true, but when one uses the concept of 'coziness' to mean something totally, undefinably human and claims that only traditional formalism could create it better than this one is on the wrong path. The criticisms, too noisy, too light-reflective, and too good a heat conductor, are in reality scientific terms for things that when put together form the mystical concept of 'cozy.' [Aalto, 1978, p 49.]

Aalto sought to arrive at a more humanely built environment by expanding the concept of 'rational.' He attempted rationally to analyse more of the requirements than had been previously connected with the objects that he created. He tried to imagine all the different requirements that can contributed to the quality of an object. These requirements formed a sort of scale, which he likened to a series similar to a spectrum:

> In the red field of the spectrum lie social viewpoints, in the orange field questions connected with the production, etc., all the way to the invisible ultraviolet field, where perhaps the rationally undefinable requirements, still invisible to us, which exist in the individual human being, are hidden. Whatever the case, it is at the end of the spectrum, where the purely human questions reside, where we will make most new discoveries . . . . Even if . . . we can find on closer analysis that an emotional concept is among other things a sum of physically measurable quantities, we still will quickly find ourselves outside the realm of physics. A series of requirements that can be made of almost every object and that up to now has been given scant consideration surely belongs in the sphere of another science -- psychology. As soon as we include psychological requirements . . . then we will have already expanded the rational method to an extent that . . . has the potential of excluding inhuman results. [Aalto, 1978, p 49.]

He extended his definition of function from the tubular steel chair to the lighting fixture, with its more direct impact on visual comfort. He felt that the traditional forms which had been derived from candlelight chandeliers and oil lamps when expressed in the era of electricity left tradition to become kitsch. The rational designers of modernism offered mostly shiny white porcelain balls and opal cubes. While Aalto recognised the functional advantages of a closed, dust free porcelain ball with nickel hanger from a manufacturing viewpoint, he was well aware of its shortcomings in 'quality of light':

> What do we mean by the light's quality? Light exists for man, a phenomenon he needs without interruption at his disposal. Properly adapted quality is much more important than in the case of objects whose contact with humans is merely temporary: an acceptable perfection from a purely

technical viewpoint -- fixtures, their movable parts, their methods of manufacture, etc., have received their rational treatment but from many different viewpoints, their main task, lighting as man's good servant, its adaptability for good vision, and in general its quality in relationship to man, has fallen behind. In this field, if anywhere, people have tried to improve upon this lack with inappropriate glued-on forms. English parchment shades with Piranesi pictures and similar things have had to represent 'hominess.'

Equally, modernism has created an enormous number of piquant chandeliers, porcelain tube-mounted lights, soffit lighting, etc. The failure to deal rationally with vision requirements and man's psychological needs is perhaps not a sin immediately recognised in an ordinary home. But if we go from the private home to, let us say, a hospital, where we have to deal with masses of people in a weakened condition, we soon notice that we cannot correct any failings with the 'cozy' remedies I have mentioned.

I have myself had experience of this in my practice. It was apparent that the prevalent hospital lighting, opalescent white bodies of light, was highly unsuitable and above all psychically irritating, even in cases where the light fixtures' glare level was reduced to a minimum. The fixtures' prevalent placement, the classical middle-of-the-ceiling principle, had to be revised, and general lighting for the room arranged solely with consideration for the sick person, his horizontal position, etc. Each solution is in some way a compromise that is most easily discovered when one considers man in his weakest condition.[Aalto, 1978, p 50.]

Aalto had considered the qualitative examination of light by spectro-analytic methods. The difficulty of creating a light with a spectrum properly adapted to humans was increased by the fact that there was such a large quantitative difference between sunlight and the then available artificial light. He suggested that if the rational approach to design were expanded so that it included technical and hygienic needs 'all the way to that borderline where the psychological needs begin,' and if one used history as a kind of statistic on how man reacts to his environment, then candlelight could be considered as a rational artificial light for man:

> the candle's yellow flame and the interior decorator lady's inclination to glorify her light compositions with yellow silk rags come closer to the mark vis-a-vis human instincts than the electrical technician with his luxmeter and his schematic concept of 'white light.' [Aalto, 1978, p 50.]

Aalto paid homage to the Japanese culture, which, with its limited range of raw materials and forms, inculcated a virtuoso skill in creating variations and almost daily recombinations, based on natural metaphors. The contact with nature and its constantly observable change was a way of life that had great attraction for Aalto because it discouraged concepts that were to his taste too formalistic.[Aalto, 1978, p 51.]

Aalto believed that technical services formed a separate and distinct group of elements within modern building. While acknowledging that the problems they solve are essentially old ones, he thought that modern technical methods freed the basic environmental systems from their old contexts and thus increased the internal freedom in building design. One example was the heating system; he was one of the first in Finland to use a district heating scheme by connecting several buildings through an underground piping system to a central heating plant. He was pleased also by the possibility of electric heating freeing buildings from dependence on each other and hailed it as one of the sources of fundamental change taking place in architecture.[Aalto, 1978, p 62.]

The Paimio Sanatorium

When he received the assignment for the tuberculosis sanatorium in Paimio, he was himself ill and therefore had the opportunity to make a few experiments and find out what it really felt like to be sick. He became irritated at having to lie horizontal all the time.

His eyes were constantly drawn to the electric light in the room 'like moths to a lamp.' He became intensely aware that the room conveyed neither 'balance nor calm' and he therefore decided to plan patients' rooms in such a manner as to provide a restful atmosphere for the bedridden patient. He did not use, for example, artificial ventilation, which causes a disturbing draft about the head, but designed a system that draws warmed air from double-paned windows (Fig. 7.2).[Aalto, 1978, p 131, 132.]

The way he arrived at his environmental solutions was through a process of research, which he considered to 'resemble' scientific methods. He held that architectural research could be methodical, but the substance of it would never be solely analytical. Always there will be more of instinct and art in architectural research. He describes the research which led to certain design conclusions for the Paimio Sanatorium:

> Experiments . . . were performed. Study of the relation between the individual and his quarters involved the use of experimental rooms and covered the questions of room form, colours, natural and artificial light, heating system, noise, and so on. This first experiment dealt with a person in the weakest possible condition, a bed patient. One of the special results discovered was the necessity for changing the colours in the room. In many other ways, the experiment showed, the room must be different from the ordinary room. This difference can be explained thus: The ordinary room is a room for a vertical person; a patient's room is a room for a horizontal human being, and colours, lighting, heating, and so on must be designed with that in mind.
>
> Practically, this fact means that the ceiling should be darker, with an especially selected colour suitable to be the only view of the reclining patient for weeks and weeks. The artificial light cannot come from an ordinary ceiling fixture, but the principal center of light should be beyond the angle of vision of the patient. For the heating system in the experimental room, ceiling radiators were used but in a way which threw the heat mainly at the foot of the bed so that the head of the patient was outside the direct heat rays. The location of the windows and doors likewise took

> into account the patient's position. To avoid noise, one wall in the room was sound absorbing, and wash basins -- each patient in the two-patient rooms had his own -- were especially designed so that the flow of water form the faucet hit the porcelain basin always at a very small angle and worked noiselessly.

These illustrations from an experimental room demonstrate Aalto's methods which had their basis in a combination of technical, physical, and psychological events, never any one of them alone. The result was a symphony of environmental control, suited to the climate and the patients' comfort needs (Fig. 7.3). Aalto's humanisation of his architecture consisted in enlarging the definition of technical functionalism to include the field of psychophysics. [Aalto, 1978, p 76-79.]

<u>The Design of Libraries</u>

Architecture takes time to incubate -- Aalto worked on the design of Viipuri for five years -- and once he had performed certain 'experiments,' he found universal application for the shapes and forms he had discovered:

> . . . I have found that a little playful experiment in forms that I once carried out and that was apparently trivial and useless, ten or more years later gave me the key to a series of shapes that were architecturally practical. [Aalto, 1978, p 97.]

With five years' time at his disposal, he pursued the solution at first with the help of primitive sketches. He gradually arrived at the concept for the library building by beginning from fantastic mountain landscapes with cliffs lit up by suns in different positions. The library's architectural core consists of reading and lending areas at different levels and plateaus, while the centre and control area form the high point above the different levels. The childish sketches might be thought to have only an indirect connection with the architectural conception, but they tied together the section and the plan and created a kind of unity of horizontal and vertical structures. [Aalto, 1978, p 97-98.]

Aalto's first use of the undulating profile which contrasts two surfaces appears in the lecture theatre at Viipuri. In this room the visual elements modify each other through the use of contrasting elements -- the white wall makes the ceiling darker. The functional requirements of lighting and acoustics which determined the undulating principle were reinforced by the wood-joining technique of parallel slats and the need for overall, spatial definition (Fig. 7.4).

Aalto defined the main problem in library design to be that of the human eye and the eye's function, that of reading a book. Any design which did not deal with this fundamental issue was 'reactionary architecture':

> Reading a book involves both culturally and physically a strange kind of concentration; the duty of architecture is to eliminate all disturbing elements. [Aalto, 1978 p 76-79.]

He knew that side-lighting in a reading room would result in diminishing illumination away from the wall, so he turned to the use of skylights; but the problem with skylights, he felt was that they gave an 'exaggerated light' if they allowed the sun to shine directly in. He solved this problem with the aid of numerous round skylights which could introduce daylight deep within the plan and constructed so that the light would remain indirect throughout the year, even during the summer solstice in Finland. His skylights typically consist of a conical concrete cylinder about six feet in diameter, and a thick jointless round piece of glass on top of it without any frame construction. These were designed to provide a kind of light suitable for reading, blended and softened by being reflected from the rough sides of the white concrete cone. The depth of the ceiling and thus the surface area of the cone become important here. The cone spreads the light in thousands of directions:

> Theoretically, for instance, the light reaches an open book from all these different directions and thus avoids a reflection to the human eye from the white page of the book. In the same way this lighting system eliminates shadow phenomena regardless of the position of the reader. The problem of reading a book is more than a problem of the eye; a good reading light permits the use of many positions of the human body and every suitable relation between book and eye. [Aalto, 1978, p 78.]

On clear days, only the upper part of the well is sunlit. This bright surface in turn illuminates the space below, as well as the remaining white surfaces within the well. Because sunlight typically strikes only the uppermost part of the well (unseen at normal viewing angles) and because the lower part of the well is smoothly curved white plaster that appears evenly bright due to the diffuse reflections within the cone, these wells have the appearance of horizontal luminous disks in the plane of the ceiling. Their true shape is apparent only when the occupant looks up (Fig. 7.5).

The conical skylight was not designed merely as the solution to visual requirements, however. In an interview, Aalto revealed that it was also the product of a structural opportunity:

> The skylight system is a combined product of the ceiling construction -- a room almost sixty feet wide needs a ceiling construction with beams high enough for the erection of the deep cones -- and special technical limits in horizontal glass construction. An architectural solution must always have a human motive based on analysis, but that motive has to be materialised in construction that probably is a result of extraneous circumstances. [Aalto, 1978, p 76-79.]

In some of his buildings, most notably the Academic Bookstore in Helsinki, as well as the library in Reykjavik, Iceland, the overhead illumination is provided by large, clear, prism-shaped skylights. The rationale behind this tall prismatic configuration was not in its increased ability to transmit low angle sunlight, but in the ability to penetrate upwards through thick snow cover (Fig. 7.6). The snow-covered lower portions of the prism act as white reflectors, in the manner of the conical skylight well.

With the development of interior skylighting cones and wells, Aalto began to make extensive use of the white reflecting surfaces of the interior as secondary sources of light. His public libraries and galleries provide examples of his integration of these light reflectors into the form and function of the building. In many of his libraries there is a sunken study area at the centre of the main library space. This creates a strong spatial focus. It also allows the important function of visual control of the stacks from the central circulation desk. This sunken area serves to keep daylighting from the perimeter above the field of view of the reader while providing more vertical illumination -- with less reduction in intensity due to the cosine law -- on the reading tables. [Moore, 1983, p 59.]

There are four visual task areas in the main reading room of the typical Aalto library: the reading counter, the sunken reading area, the stacks, and the charging desk. A large, high, usually south-facing window with clear glazing is the dominant natural light source. The largest of his libraries is also the furthest north at Rovaniemi -- sitting a short distance from the Arctic Circle -- which presents a great challenge for daylighting in the wintertime. The glass area devoted to perimeter daylighting appears to be quite large, leading to considerable winter heat loss, while admitting large amounts of diffuse daylighting. The 'light scoops' act as internal brise soleil, protecting the spaces from most high-angle direct sunlight, glare and overheating in the summertime. As Moore noted, even at this high latitude, reflective film has been added to the east and west glazing to reduce summer solar heat gain. [Moore, p 63.]

In the smaller library at Seinajoki, the glazing is protected with horizontal, diagonal exterior louvres, white on both sides. They act to 'cut-off' the sun when it reaches an angle greater than 45 degrees. At angles higher than 45 degrees, sunlight is reflected twice by the parallel louvres. As a result, the high window performs like a translucent diffuser to summertime light. Its large area illuminates the reading areas from above the field of view of the reader, resulting in generous illumination evenly distributed, and because of the high location of the source, it has little cosine reduction, and minimal glare.

Winter sunlight enters directly, most of it striking the lower part of the large, curved and reflective surface of the light scoop. The lower portion of this scoop has a high luminance level, due to its orientation relative to the window. This bright surface becomes the principal source of illumination for the vertical book stacks along the exterior wall. The scoop has a large apparent size as 'seen' from the stack. It is not as obvious from the section that the book stacks perpendicular to the wall receive diagonal illumination from the scoop as well as direct illumination from the window, since the wall curvature is fan-shaped in plan. The luminance of the scoop is also important in reducing brightness contrast around the window. [Moore, p 61.] The charging desk has poor daylight illumination because most of the south window is obstructed by the eyebrow and the north clerestory is directly overhead. This results in a small apparent size of each source from this location. Apparently the structural requirements of the building prevented the placement of the north clerestory even further to the north, which would have increased its apparent size and thus the illumination in this area. However, the sloped ceiling receives light reflected from the snow on the adjacent roof and, to a lesser extent, directly from the sky.

In the Wolfsburg Civic Centre, the library is only one of several functions in the larger building and the dramatic exterior forms and interior spaces are limited to the series of lecture rooms. To maintain a low profile in the library, Aalto used smaller roof monitors with scoops to illuminate the perimeter stack area. These are oriented east, southwest, and northwest with 70 degree clear glazing. There are no exterior louvres for sun control, due to the predominantly overcast local climate. Penetration of direct sunlight is minimised on clear days by the pronounced curvature of the scoop. Thus the backs of the scoops receive either direct sunlight or diffuse skylight, and become secondary sources for illuminating the adjacent perimeter stacks.

Summary

Aalto differed from the orthodox European rationalists of his time in striving for an aesthetically perfect form; nevertheless, he went his own way towards humanising, creating climatic sensitivity and injecting emotional values into his architecture. Aalto designed environmental tempering systems integral with the form of his architecture which met physical and spiritual needs and provided both comfort and inspiration. The harmonious way in which his architecture derives comfort and delight from difficult climatic conditions is remarkable. In addition, he successfully used many of the same principles in designing for less hostile climates. These systems of control were not discovered by accident but rather arrived at over years of careful experimentation, observation, trial and error. Although his work became one of the incentives for the advance of architecture in northern Europe after the war, as in much architecture of the well-tempered environment, the forms and massing of his designs were more influential than the specific ways in which his buildings dealt with light, heat and sound.

Thermal and visual comfort were uppermost considerations in his designs. His libraries are a refinement of the idea of primary and secondary sources of daylight and artificial lighting which meet the functional needs of the reader. It can be said that these systems of environmental control gave shape to his architecture, inasmuch as the forms for skylights, windows, reflecting surfaces, solar shading, lighting fixtures and other environmental equipment become major expressed architectonic elements in most of his buildings. Aalto's fully developed architectural expression provides more than closure. It admits and modulates -- or keeps out -- the climatic elements, making possible an architecture derived from a high order of climatic sensitivity.

However, these elements of environmental tempering are largely inseparable from the whole in Aalto's work. It is difficult to attribute by cause and effect the proper origin of his architectural forms. He wove the carefully honed systems for controlling light, heat and sound into the fabric of each of his creations in such a way that one can hardly be separated from the other. This is in contrast to the nature and substance of Le Corbusier's nearly distinct morphemes for environmental tempering, which could be more universally adapted to other designs.

8. Louis I. Kahn: The Light of the Room Itself

Kahn has been described as the 'prophet of the suppressed generation,' since the ideas he held could not be developed or put into convincing practice during the period 1925-1960 because of the unfavourable -- if not totalitarian -- aesthetic climate which had been created by the reigning masters of the Modern Movement. [Jordy, 1974 p 318.] At the end of the 1950s there began in the United States a slow process of replacement. The great German architects of the interwar years, the influential teachers of architecture in America in the thirties and forties -- Breuer, Gropius, Hilberseimer, Mies van der Rohe, Moholy-Nagy, Wachsmann, Wagner -- if they were still alive, gradually retired from their teaching posts. Younger men such as Kahn, born in 1901, who taught at Yale and the University of Pennsylvania, took their place.

For Kahn, as for Le Corbusier, the engineer's craft, as interpreted by the architect, was seen as having a unique role to play in the development of architectural form. In the words of the slogan around which the thesis of Vers Une Architecture was organised, Kahn was concerned about the appropriate balance between 'the engineer's aesthetic' and architecture. With a strong footing in the French rationalist tradition, Kahn's lifelong quest was for architectonic elements of indisputable authority. His attitude toward structure and technology has been described as being equally close to both Viollet-le-Duc and Buckminster Fuller. [Frampton, 1980, p 22.] Kahn's approach to structural form and his strong views on technology and classicism return us to architects at the turn of the century who anticipated his expressions. Labrouste, for instance, in the Bibliothèque St. Genevieve used advanced technology in a traditionally classic context.

The impact of environmental tempering on architectural form in Kahn's buildings contains, if it is possible to imagine, elements of Wright, Le Corbusier, Mies and Nero's Golden House! Several of his buildings support this notion, including: the First Unitarian Church, Rochester, N.Y.(1956-64); the Richards Medical Research and Biology Buildings for the University of Pennsylvania, Philadelphia (1957-61); the Salk Institute of Biological Studies at La Jolla, California (1959-65); the Kimbell Art Museum at Fort Worth, Texas(1967-72); and the Library for Phillips Exeter Academy in Exeter, New Hampshire (1967-72).

Kahn's design activity overlapped that of Frank Lloyd Wright. One of Wright's last buildings, the Guggenheim Museum, was under construction during the same years as the Richards Medical Research building, Kahn's first building of major importance. Kahn's building owes a formal debt to early Wright designs, yet there were great differences between the two. Wright drew strength from American poets and writers such as Emerson, Thoreau, Melville, and Whitman; from the ideals of Jeffersonian democracy, and from the spirit of the American Plains Indians, where Wright set his houses joining the earth and the sky. For Kahn and his generation, these sources had lost their vitality. In the post-war era, there was moral uncertainty and loss of spirit. It was a time of corporate anonymity and bureaucratic banality. It would have been nihilistic for Kahn to have created an architecture interpreting such events. He turned instead to the eternal -- the 'archaic' -- to that which transcends the circumstances of any given moment, where he 'found Order' and from which he 'brought Spirit' back into the world. [Lobell, p 3.]

Wright's seminal influence is seen most clearly in Kahn's First Unitarian Church, the Richards Laboratories and the Exeter Academy Library. The Unitarian Church and Exeter Academy Library seemingly take their square theme from Wright's Unity Temple. The shaft/service structure of the Larkin Building re-emerges in the Richards Laboratories as a series of 'served' laboratory towers suspended within a 'servant' latticework of structural piers and masonry service ducts. Wright's facility with the elemental methods of the Beaux Arts, i.e., the Durandesque tartan grid, are echoed by Kahn in the structural grid of the Yale Art Gallery and in the modular planning of the Richards Laboratory.

But the similarity to Wright was probably unconsciously achieved, and the fundamental differences between the two architects are revealed on closer inspection of Kahn's work, for instance the Bath House for the Trenton Community Center, 1955-1966, which was the germinal project of Kahn's rise to importance. The volume-defining hipped roofs recall those used by Wright in his Hillside Home School, 1902. In both cases the roofs are supported by massive piers. However, Wright's piers were solid, Kahn's hollow. 'Today we must build with hollow stones,' Kahn said in 1957, and for a clear reason; to house the services. Just as Wright came to use hollow piers housing utilities in his Unity Church, Kahn developed this idea as a preform of ancillary spaces in his buildings.

Kahn's pure geometrical forms recall those of Le Corbusier, but most of all the Roman and Mediterranean tradition behind them. The rounded arched voids with a slot below in the Fleisher House project of 1959 is found at Ostia, which was visited by Kahn in 1950.

The First Unitarian Church

As much as any other design of Kahn's, the First Unitarian Church embodies a strong relation between space, structure and light (Fig. 8.1). To a lesser extent, the relation between servant and served seen here in its germinal state -- there is less of a need for this relationship in a building of this type. The church demonstrates the power of the 'preform' of light, as Kahn called it, to define the clerestory roof-lighting elements which give shape to the square sanctuary below (Fig. 8.2). Guarding against the glare of direct light, Kahn designed a series of vertical baffles which act also as structural buttresses to shield the windows from direct light and cause it to reflect off the reveal and indirectly on the side of the wall. Within the spaces formed by these baffles, he placed window seats for sitting in the soft light. This arrangement is reminiscent of the social advantages of the inglenook.

In his first sketch for the design, Kahn started with the preform of the square sanctuary in the centre, surrounded by an ambulatory which is in turn wrapped by school rooms and work rooms. He then allowed the preform of light to develop until it defined the space and structure. This is a clear example of the derivation of form from the beginning argument of light and its interaction with structure.

The Richards Memorial Laboratory

The Richards Memorial Laboratory is perhaps Kahn's best known building and it fits the nominal definition of the architecture of the well-tempered environment, though paradoxically it fails at the human scale to deliver environmental comfort. In its use of monumental form for environmental tempering, it makes classical references, and it demonstrates Kahn's constant preoccupation with the technical and tectonic authority of the constituent elements from which building had to be compounded -- the ducts and pipes and piers of service and support.

Kahn's building diverges from Wright's Larkin Administration Building in its avoidance of the knitting of fragmented parts together. In a Miesian way, he enhances the accentuation of the discreteness of parts by combining them bluntly, side by side. However, the box-like elements, together with the stacks of individual studio laboratories, do not resemble Mies' 'universal' forms and spaces, into which all functions could be fitted. Instead, the design gives way to a more complex mass, defined not as large, multi-useless spaces but derived from the implied structure of light and air and water that circulate in the service networks. About these functions and the powerful role of light in forming his architecture, he had this to say:

> If I were to define architecture in a word, I would say that architecture is a thoughtful making of spaces . . . Even a space intended to be dark should have just enough light from some mysterious opening to tell us how dark it really is. An architectural space must reveal the evidence of its making by the space itself.
>
> Each space must be defined by its structure and the character of its natural light. It cannot be a space when carved out of a greater structure meant for a greater space,

because the choice of structure is synonymous with the light which gives image to that space. Artificial light is only a single, tiny, static moment in light and is the light of night and never can equal the nuances of mood created by the time of day and the wonder of the seasons.

Structure is the maker of light . . . A plan of a building should read like a harmony of spaces in light. [Whiffen, p 426.]

Kahn was plainly inspired by Le Corbusier's famous aphorism and the final sentence above echoes the familiar definition of architecture as the 'wise, correct, magnificent play of masses in the light.' However, Kahn significantly shifts Le Corbusier's emphasis on 'masses' to 'spaces.' In other words, he felt that interior uses rather than external aspect should determine the sculptural quality of the building.

No aspect was more immediately important to Kahn than that of giving prominence to a building's mechanical services. If the architect is not to relinquish control of an increasingly important part of the modern building to the mechanical engineer, the service appliances must be provided for from the start. Kahn's feelings towards the 'mechanics' of the building was unequivocal:

The mechanics -- all those pipes and ductwork, are a destroyer of architectural spaces. Most of our columns end up festooned with them, or alternated with fake columns of them. They destroy the clear picture between a column and no-column . . . . I've hated mechanics, but I've learned to respect it because it's a destroyer. [McQuade, 1957, p 141.]

In this building, the mechanical installations were all exposed to the spaces below. One of Kahn's associates described the effect:

After the first floor piping was in place, it looked terrible: the pipes crisscrossing at different elevations, some of them running diagonally, no order whatsoever. Kahn seeing it became mad, if not directly hysterical. He stopped the installation, called the mechanical engineers and his own assistants, and gave them hell. The already finished work was dismantled and the piping arranged so that

> some order was obtained. It created a lot of confusion and bad blood with the contractor and the mechanical workers. [Komendant, p 23.]

In later work, Kahn did not advocate exposed mechanical systems.

In the Richards Laboratory, the allocation and distribution of functions and forms appropriate to Kahn's philosophy makes his intent perfectly clear (Fig. 8.3). The function of the stacked, square tubes has been explained by both Banham and Jordy. [Banham, 1969, and Jordy, 1972, p 394-95.] The four air intake stacks (I) suck outside air through large rectangular openings, whereas the exhaust flue stacks (F) carry noxious fumes from the laboratories, to be discharged well above this and neighbouring buildings. and far from the air-intake 'breathers' placed low at the rear of the core block. The stair towers are unnecessarily brought to the height of the exhaust stacks but the different function is signalled by cleaving the former into vertical slabs (Fig. 8.4)

As Banham has observed, the exterior mass of the utility towers possess a largeness, blindness, and mystery wholly inappropriate to the scale and purpose of the utility channels that are contained inside. Early in the design phase, Kahn did attempt to mold the exhaust towers a little more closely to their intended function. In variant schemes they were fluted or stepped out, floor by floor, at the lower levels of the building so as to indicate the progressive enlargment of the area of stack required to contain exhaust vents as these entered the stack from each laboratory shelf. The early designs were rejected for a bolder form which brought the building more firmly to the ground.

All of these vertical servicing towers leave the laboratory platforms completely free of vertical utility runs. The exposed utilities in the webs of the space-frame ceilings of the laboratories are another, more explicit instance in which Kahn bowed to the visual strength of the mechanical systems of this building. It was the tetrahedron ceilings in reinforced concrete of the Yale Art Gallery, with the exposed equipment threaded through the triangulated spaces, for which Kahn was best known immediately prior to his commission for the Richards Building (Fig.8.5). Once they had moved into the Richards Building, some scientists masked the invigorating presence of the latticed interweaving by installing ceiling panels in the microbiology laboratories where freedom from dust is necessary.

The size of each laboratory platform in the Richards Building is determined partly by plumbing requirements, partly by the need to accommodate laboratory benches 185 mm wide with 1.5 metres of working space between them. The supporting columns and the towers are juxtaposed with the windows to create a cross-shaped area of relative shadow toward the center of each laboratory studio. This shaded area can be partitioned for storage, incubators, cold rooms, photography, etc. Major work areas occur in the lighted corners which are made possible by the cantilevered slabs.

The corners are where the major environmental shortcomings are found. Sun control -- against glare and outside heat -- is not provided by the tinted pale blue glass. The windows have instead been treated by <u>ad hoc</u> remedies ranging from Venetian blinds, external metal mesh screens and unit air conditioners to a patchwork of insulating board and aluminium foil in order to shield the scientists and the delicate instruments inside. This diminution of functional purity in Kahn's statement in 1961 is an ironic reference to the architectonic solution which eluded Le Corbusier in his Cite de Refuge thirty years earlier in Paris.

The Kimbell Art Museum and Phillips Exeter Academy

Both the Kimbell Art Museum and the Library of the Phillips Exeter Academy begin with identical starting points, i.e. the concept of the unit of space -- the smallest indivisible spatial unit in the building -- as an increment of function. In both, Kahn defined the unit of space as being 'an increment of light.' The importance which Kahn accorded natural light was the subject of a talk which he gave at the opening of the Kimbell Art Museum:

> When a man says that he believes that natural light is something we are born out of, he cannot accept a school which has no natural light. He cannot accept a movie house, you might say, which must be in darkness, without sensing that there must be a crack somewhere in the construction which allows enough natural light to come in to tell how dark it is. Now he may not demand it actually, but he demands it in his mind to be that important. [Kahn, 1975, p 39.]

For the Museum, the generative element is a long gallery with a light slot at the top; for the Phillips Exeter Academy Library it is a study cubicle beside a window. In short, the starting points for both buildings were faithful to Kahn's familiar fundamentals:

> The room is the beginning of architecture. A plan is a society of rooms. The light that enters the room should be the light of that room itself. [Jordy, 1972, p 331.]

Although Le Corbusier periodically used low vaults in series, he used them in ways very different from Kahn's use of them at the Kimbell Art Museum. Typically, as in the Monol Housing of 1920, and its many variations, they were conceived of as walled tunnels, even where the lateral walls were variously broken through as in the Jaoul and Sarabhai houses of 1954-56. Kahn used lighted strips to illuminate the ceiling of his vaults in the museum, where Le Corbusier referred to the vault as a tunnel wall or compartment accentuated by lighted ends. In the Kimbell Museum, the top lighting seems to encourage movement across the vaulted space as much as along it (Fig. 8.6).

The linearity of the service system -- air handling and lighting -- is in harmony with the long galleries in the museum. Although the basic design of the natural lighting system which runs along the top of the barrel vault came from Kahn's office, the details of the system were painstakingly developed through the research of Richard Kelly and the technical design and fabricating skills of Edison Price. [Plagens, 1968.] The strong Texas light is diffused and re-directed down the curve of the vaults, and out toward the paintings, while it is filtered simultaneously by drilled aluminium screening to compensate for the darkness of the center strip which would otherwise occur. Solid shielding, directly under the light slots in gallery vaulting, is narrowed in the entrance gallery so that here the bright light of the sky easily passes through the aluminium screen, thereby subtly increasing the intensity of natural illumination in the area that serves for foyer and sales desk.

Kahn's fervour for natural light matched that of the director, Dr. Brown, who saw the primary dependence on natural light as another means of giving the museum a house-like quality. Kahn characterised the creation of the gallery lighting system as 'painting born in the light of day . . . Here each room has the light particular for that day.'

The massing of the forms of the Library at Phillips Exeter Academy, reveal four 'servant' towers which define the corners of the central atrium, with two zones wrapped round (Fig. 8.7). As in the First Unitarian Church, the design of the Library began on the periphery with the circle of individual window carrels, each with its separate window -- 'A man with a book goes to the light,' Kahn had written earlier. Kahn saw the carrel as belonging to the outside world (Fig. 8.8). He thought that 'occasional distraction is as important in reading as concentration.' [Jordy, 1972, p 333.] Le Corbusier comes to mind when one first experiences Kahn's building, not only because of the sculptural quality given by the play of light on large unbroken surfaces, but also because sculptural complexity is given to the building by Kahn's concern for breaking up the institutional lump into human-sized compartments. The carrels in the Exeter Academy Library are to Kahn as the maisonettes at the Unite d'Habitation were to Le Corbusier. Kahn's image however is more faithful to its brief than to the somewhat arbitrary, prisme pur aesthetic of Le Corbusier. Kahn's building, in his phrase, 'insists on what it wants to be,' and the carrel -- and its light -- was the spatial common denominator which generated the rest of the building. Kahn carefully defined the nature of spaces thus generated:

> No space, architecturally, is a space unless it has natural light. Natural light has varied mood of the time of the day and the season of the year. A room in architecture, a space in architecture, needs that life-giving light -- light from which we were made.
>
> Architecture has no presence, music has no presence -- I mean of course the Spirit of Architecture and the Spirit of Music. Music in this sense, as in Architecture, favours no style, no method, no technology. Form, when realised, does not belong to its realiser. Only its interpretation belongs to the artist. Form is like order. Oxygen does not belong to its discoverer. [Kahn, 1969]

For the central atrium, Kahn wanted a top-lighted, empty space to provide a central, generalised light with the books visible all round, in contrast with the specific task lighting of the peripheral windows. In effect he returned to the spectacular central-courted libraries originating in the 17th century and fashionable through the 19th.

In part to nurture the lighting effects -- the play of light on surfaces -- he was committed to the use of traditional materials in this as in his other buildings. His intense feeling was that the building was a 'harbouring thing' and this prejudiced him against the brittle thinness which came with excessive use of metal and glass. [McQuade, p 135.] The play of light on the rougher, 'archaic' texture of masonry and reinforced concrete construction gave his buildings a visual force which makes the usual metal-and-glass wall seem insubstantial:

> Of course, steel is a marvelous material. You can do wonderful things with it, build great machines, but in architecture you're not building airplanes after all, are you? [McQuade, p 136.]

The Salk Institute

The Salk Institute, located in the Mediterranean climate of La Jolla, California, is one of the major high art monuments of California. The complex is highly formal, in some ways Beaux Arts, and in its dramatic use of water and concrete forms, classical in nature. Two banks of buildings face on to a central court which, on the inland side, axially terminates in a gate and steps, and on the ocean side in walls, steps, and fountains (Fig. 8.9) As with all of Kahn's buildings, the bank of laboratories to the south and individual sawtooth laboratory-offices to the north unite pure form and utility:

> When Salk came to my office and asked me to build a laboratory he said, 'There is one thing which I would like to be able to accomplish. I would like to invite Picasso to the laboratory.'
>
> He was implying, of course, that in science, concerned with measurement, there is this will of the least living thing to be itself. The microbe wants to be a microbe, the rose wants to be a rose, and man wants to be man; to express. This desire to express was sensed by Salk: that the scientist needed the presence of the unmeasurable, which is the realm of the artist. [Lobell, p 76.]

It is ironic that Salk later married Francoise Gilot, the woman who had lived with Picasso for 18 years.

In continuing the notion of strains of Oriental influence in the environmental attributes of work of Wright, Le Corbusier, Aalto and Kahn, the Salk Institute can be conceived of as a mandala. [Lobell, p 76, 89.] In Oriental art, the mandala represents natural order and hierarchy through the use of a series of concentric geometric shapes, each containing an image of a deity or an attribute of a deity. In Jungian psychology, the mandala is seen as a means of re-unifying the various aspects of the self. Kahn's building becomes introspective as it moves inward from the exterior utility spaces containing staircases and toilets; through the hermetically sealed laboratory spaces -- where the biological research takes place -- monitored by computer, and served by large spaces for ducts and equipment (the body); through the walkways, which are places of human interaction (society); through the private, teak-screened offices of the scientists with their ocean views, which are places of contemplation (the mind); to the central court with a simple band of water running through it, which is a 'place of stillness, of silence', a 'roofless cathedral' (spirit). Thus, the progression from body, society and mind to spirit ranges cybernetically across the attributes of the whole human being. Kahn realised that a great building must serve these functions harmoniously. He had witnessd the fascination of Modern architecture with the machine-like quality of the glass box. In designing the Salk laboratory, Kahn also used glass to enclose the work spaces, but he then encased the glass in concrete -- as if he were wrapping it in the rich forms of history.

The Salk Institute Laboratories strike a more satisfactory relation between form, structure and space than the Medical Research Building. Here the 'servant' spaces are subordinate to the 'served' laboratory space and integrated with the structure, entrance and exhaust stacks, thus achieving a continuous relationship between them. In the Salk complex the laboratories occur in three-storey blocks -- one storey being below ground level -- with broad, open floors. The ductwork for services runs overhead, threaded through the trussing that supports the floors, and spans the space from wall to wall. An early drawing shows this resolution at the formal level (Fig. 8.10).

<u>Summary</u>

By his own admission, Kahn's control over the form of environmental tempering arose from a distaste for mechanical systems. Where light, air and sound were functional issues, he first derived through design the pre-form of the climatic variable. He then used pure forms to achieve environmental control. He defined the smallest divisible spatial unit in a building as being based on an increment of light. In this way, it can be said that his forms were derived both from the nature of the environmental force and the function of his architecture in providing comfort and inspiration to the user. In the control of light, it was not only the geometry, but the use of materials which enhanced the function by providing texture and substance lacking in the concrete, metal and glass of his contemporaries. The results of Kahn's work were influential to a generation of architects, notwithstanding the environmental shortcomings in some of his buildings.

9. Environmental Tempering After Modernism

One can no longer use the word 'Modern' to describe architectural design today. Modernism and the International style that architects fought for in the 1920s have been overtaken, since 1960, by Regionalism, Late-Modern, Modern-Organic, and High-Tech styles, among others. These styles are based on the search for cultural expressions of function and comfort in architecture. In most cases the new styles respond to some of the earlier criticisms of Modernist buildings which were likened to dry and lifeless machines for living and working. In addition, Post-Modernism has emerged in the last decade as a style which makes a break with Modernism [Jencks, 1984]. In Post-Modernist architecture, with its classical references, climate, comfort and services are not usually primary design considerations.

In the following pages, representative architectural works from each of the styles mentioned above will be described and evaluated for their provision of environmental tempering. Concluding remarks will follow on the art and science of environmental tempering in architecture.

Regionalism

In Third World countries which served as proving grounds for the International style, there is now a pervasive reaction against it as architects search for regionally appropriate styles. The new Regionalism attempts to replace what Modernism conspicuously removed, i.e., continuity between past and present forms of building. The work of Regionalist architects such as C. M. Correa and Lucien Lafour represents the re-discovery of a design idiom hidden in neglected vernacular traditions which are suitable to local climate, customs and available materials.

Charles M. Correa, one of India's leading architects, designs in a climatically sensible style which blends indigenous and ancient traditional forms, whilst using regional materials and construction techniques. Correa contends that the energy shortage of the 1970's should encourage architects to reconsider the importance of climate as a generator of architectural form. His intentions are shaped by practical, economic constraints as well as by vernacular forms and lifestyles. He describes the reality and the pleasure of working under these difficult conditions as follows:

> We simply can't afford to squander the kind of money -- and energy -- required to put up a glass tower in a tropical climate (or in most other climates for that matter). And this, of course, is an advantage, for it means that the architecture itself must create the 'controls' which the user needs. Such a response necessitates much more than just sun angles and louvres; it needs must involve the section, the plan, the shape and the heart of the building.
>
> Because of this, a country like India is really a pleasure for an architect to work in. It is one of the few occasions left when the two (contradictory) compulsions that precipitated Modern architecture can be synthesised: namely, on the one hand the credo that function, however broadly defined, is the progenitor of form; on the other, the usually compulsive fascination that architects have always felt for new and exotic form. Thus, too often, an office building in New York is made interesting, as Mies pointed out, only at the expense of being good.
>
> But here in India, one is dealing with a unique set of social and economic conditions, climate, living habits, materials and so forth. In other words, the kind of occasion which without contortion, without exaggeration -- must sooner or later surely precipitate new forms, new patterns, new techniques -- in short: a new landscape [Contemporary Architects, p. 167.]

Correa's design for the capital complex for Emperor Akbar at Fateh-pur-Sikri is not only an architectural tour de force in the classic sense of scale, proportion, silhouette and materials; it is also designed to be at least

10 degrees cooler than the surrounding landscape (Fig.9.1). Hence the pattern of open pavilions, placed formally in the context of courtyards, inlaid with fountains and running water. Correa stresses comfort as the generator of architectural form:

> Sensational as this architecture appears against the evening sky, it is only when you are within that you comprehend the fundamental impulse (the architectural deep-structure) that generates the form. It is the necessity to control luminosity, air movement and temperature; in short, to establish a micro-climate (and hence, a life-style) for its users.

Correa also achieves comfort in a design for a series of narrow rowhouses by providing for changing patterns of use from one season to the next. To accomplish this, Correa designed two basic sections, a 'summer section' and a 'winter section' (Fig. 9.2). The first creates a pyramidal interior space by closing off the sky. This configuration is best for hot afternoons. The winter section is a reverse pyramid, opening up to the sky for use in the cold season and in the summer evenings. By exploiting these planning principles, Correa draws from hot-climate vernacular prototypes such as the polycentric arrangement of mud huts in an African chieftain's compound to the marble pavilions of the Mughals.

These prototypes control climate by creating a nomadic lifestyle for the occupants, with particular spaces being used at different times of day. The pattern can also vary with the seasons of the year. For instance, in Correa's design for the Agra Fort, a velvet curtain is stretched across the courtyards in the early morning during the summer months, trapping the cold night air in the lower level of rooms (Fig. 9.3). In the evening, the purdah is removed and the Emperor enjoys the evening in the cool pavilions and gardens of the terrace levels. In the cold but sunny winter, the pattern is reversed: the terrace garden being used during the day, and courts and lower levels at night. According to Correa:

> To be inventive about <u>climate</u>, one has really to be inventive about life-style. All truly <u>new</u> architecture and planning, in the final analysis concerns the conception of an alternate life-style. To reduce a challenge as magnificent as architecture to a mere juggling of surfaces and textures is bathos indeed. It is a symptom of the crippling myopia that has affected the modern architect for the last decade or two; that is to say, ever since he handed over so much of his legitimate responsibilites to his mechanical engineers.

Another Regionalist architect, Lucien Lafour, designs contemporary, climatically responsive buildings for the tropical climate of Surinam. His most important design so far is for the Marienburg Health Center, built on a former plantation across the Surinam River from Paramaibo (Fig. 9.4). Located just 5 degrees north of the equator in the former South American Dutch colony, the average temperature is 27 degrees C. The maximum midday temperature is 31 degrees C, and at night the minimum temperature is 23 degrees C. Average unobstructed sunshine is 60 per cent, rainfall is 2000 mm per year, relative humidity is 90 per cent and the prevailing wind is a gentle north-easterly.

Design for air-conditioning would require a highly insulated and airtight building. However, this is beyond the reach of most in Surinam. In Lafour's health center, air-conditioning is installed only in rooms with sensitive instruments. Lafour's design strategy achieves comfortable internal conditions by exploiting the climate to maintain constant air movement (Fig. 9.5). The design invites the wind by proper positioning of the rooms with walls and roofs shaped and perforated to encourage air flow. Timber walls are used for their low thermal capacity and high insulation value, and an east-west orientation lessens the amount of sunlight beating on wall surfaces and draws in the prevailing northeast breezes. Heavily insulated, pitched, overhanging roofs shade the walls from the direct overhead sun in the east and west elevations, providing shade and shelter. Vertically pivoted windows and a double bank of louvres which act as ventilating monitors along the elevated ridges of the roof, make them into motionless, built-in fans. Ceilings of public areas slope up to the ventilators, while internal rooms have flat ceilings. Reducing direct sunlight and admitting cooling breezes into the building have generated distinctive forms. Aldo Van Eyck has described the inviting nature of the clinic in this way:

> It receives people from roundabout as generously as it collects the rain from above; the 'gutters' are at the same time overhangs for the concrete verandahs underneath. These bear the striking timber roofs that function like enormous lungs. In the tropics uncomfortable numbers of people often have to wait very long and patiently for something which sometimes does not even exist -- in dust and scorching heat.
>
> Someone who is tired and anxious and attends Lucien's clinic at Marienburg is already less badly off, because of the way the building receives him and makes him feel at home.'

The clinic proves that even in difficult climates, comfort can be created through sensitive design without help from costly, complicated mechanical systems.

Late-Modernism

An examination of the differences in style emerging in the 1960's reveals the persistence of the Modernist tradition. The earlier ideas and forms have been taken to an extreme by Late-Modernists, where the technological image is exaggerated to create a new aesthetic.

Wurster Hall at the University of California, Berkeley, pioneers the Late-Modernist movement in America. This brutalistic building by Joseph Esherick, which contains the College of Environmental Design, retains a sense of ambiguity while tending to environmental function. The climate of Berkeley is not difficult, although during the winter the skies are overcast and during the summer there is a potential for overheating. Wurster Hall achieves a remarkable climatically-responsive function by a pattern of solar shading and fenestration (Fig. 9.6). The unself-conscious expression of function is seen in the height of exterior window sills which varies to accommodate the lighting needs of the rooms without reference to massing or alignment with adjoining windows.

Utterly utilitarian, it was described in Architectural Forum as a 'wonderland of perhaps premeditated but evidently uncensored mechanical happenings.' The plumbing, ventilation and electrical conduits remain exposed and the walls are either of dense, smooth concrete or rough-surfaced redwood plywood panels. The various shapes and forms, including a ten storey tower, are juxtaposed in a casual way, achieving coherent identity with little effort. The building stands as testament to Esherick's belief that architecture should not attempt a series of compromises to resolve conflict but should preserve oppositions and tensions.

Esherick has developed a tradition of environmentally responsive architecture, exhibited in his northern Californian residential designs. Several of his designs are distinguished by pergola-like shading devices that project out above each window. This innovation supplants the function of the traditional roof with overhanging eaves. A good example of integrated environmental tempering is found in the design for the McIntyre house, which features a central living space covered by a 'rooflight. The concrete beams that support the glass roof also serve as gutters in rainy weather.

Christopher Alexander. Christopher Alexander is a theoretician, academic and practitioner who explores the cultural basis for an architecture of function and comfort. Two of Alexander's recent Californian houses stand as a small but growing testimony to his vision — to create those qualities that go beyond stylistic capriciousness to achieve environmental comfort, simplicity and a deep sense of well-being. The Sala house in Albany, California (Fig. 9.7), is an example, about which it has been said that simplicity and comfort neither arises from the 'undernourishing Modern nor that of the recently overstuffed' [Fromm, 1986].

The Sala house has thick walls and sturdy columns, bright colours never fainting to pastels, an informal plan with an inglenook, an abundance of alcoves, and windows which all add up to give a cosy, well-lit feeling of simplicity and comfort and an appearance of being a pleasant place to live. The result is a design that is straightforward, with each structural and ornamental feature stemming from Alexander's Pattern Language. Alexander believes that form and function must be inextricably related to each other:

> The notion that on the one hand there is function and on the other hand appearance is exactly the problem of the Twentieth century. Design becomes like cosmetics, and I don't think you can get decent architecture out of a process in which you have that kind of split.[Fromm, 1986]

Alexander's design technique has been described as existential. He has a tendency to make decisions in situ, with the aid of numerous studies, models and pre-enactments with the client. For instance, he describes the selection of a certain colour to be used at the entrance:

> The question was what colour... would produce a completely peaceful harmony with what is there. I guessed at a colour, an apricot yellow, then tried a darker yellow, but realised it wasn't creating that feeling of 'light' I was aiming for. I did various colour mock-ups. The greyish pink-rose was a surprise, but the whole situation there seemed to be brought into life with that colour.[Fromm, 1986]

Alexander's theories extend beyond architectural aesthetics to consider the issue of wholeness and values which he claims will lead to a universal system of judgement about good and bad design. In many specialist fields such as ecology and physics, a more holistic and embracing view of the world is emerging. The estrangement and disaffection of man towards society and nature, his habit of over-concentrating on one segment to the detriment of the rest, is being questioned. Alexander believes architects are at the forefront of scientific discovery:

> We are in an occupation that is more responsible than any other for building the world, and the nature of the world is more fundamentally important to us than to anybody else.
>
> It will be a very interesting and shocking turnabout when we find that these questions coming from architecture have more to say about the nature of the world, and the nature of things, than those rising from biology and physics.[Fromm, 1986]

This idea is relevant to a discussion of the relationship between art and science in design, which will occur at the conclusion of this chapter.

Arup Associates. Arup Associates demonstrate their dexterity at regionally appropriate architecture in the Late-Modernist style in three recent projects, one in Nigeria, the others in the U.K. Their 1978 project for the School of Mining in Jos, Nigeria, is a regional solution to a demanding climate and the budgetary limitations of the Nigerian Department of Mines. The prominent formal expression in the design is the roof ventilator which induces air flow in the occupied classroom and convective air circulation through the double roof structure (Fig. 9.8).

Also in 1978, Arup Associates designed a new South West Regional Headquarters of the Central Electricity Generating Board in Bristol. The support structure, services and building envelope are rationally integrated (Fig. 9.9). The engineering feat of moving waste heat generated by lighting, people and equipment to the employee swimming pool provides an added amenity during winter-time.

A more recent design by Arup Associates is an immaculate eight storey office building on a high-density urban site in London. An enclosed atrium at the heart of the building is representative of the innovative use of this type of spatial element in many recent commercial buildings. The atrium carries with it some environmental advantages, mainly the improvement in daylighting of interiors. The greatest benefit in spatial organisation is that a huge floor area can be wrapped around the atrium, creating a deep building low in height and visual impact, and yet in which all parts are close to natural light and a pleasant outlook. Ingeniously, the constant width floors step back from the perimeter at the upper levels as they step into the atrium (Fig. 9.10). Therefore, the main facade of the building appears to be only five storeys, which matches the height of the neighbouring buildings along Wilson Street.

Richard MacCormac and Rick Mather. Richard MacCormac's design for Fitzwilliam College, Cambridge, allows every student room a corner window because of the stairwell configuration, which at the same time causes the appearance of wave motion on elevation (Fig. 9.11). Externally, each window bay is treated as a little building. Internally, a Soanian effect is achieved in these spaces which are reminiscent of the carrels in Kahn's Exeter Academy Library; special places beyond the expected confines of the everyday room. [MacCormac, 1986B, p. 18].

At the Sainsbury Building, Worcester College, Oxford by MacCormac, Jamieson and Prichard, one of the starting points for the design is the basic unit of the plan, the student room. The theme of the room, or even the space around the window, as a generator of form harkens back to the words of Louis Kahn, who wrote:

> I think the most inspirational point from which we might try to understand architecture is to regard the simple room as the beginning of architecture. You know, when you enter your room, how you know it like no one else knows it. Maybe it's the windows that are the most marvelous thing. [MacCormac, 1983 p.61].

At Worcester, each bedroom, even though identical in plan to its neighbours, has a different orientation which provides an individual atmosphere, as the natural light enters the room at different times of the day (Fig. 9.12). The bay window with a shelf replaces the fireplace as a focal point for life within the room. A post-occupancy survey of students revealed some dissatisfaction with the natural lighting by those whose rooms were poorly oriented, or who had windows on the internal corners which are quite narrow. Acoustic insulation is good, due to the carefully detailed design, however, the irritating squeaking of door hinges in quiet surroundings made some students believe the acoustic insulation was unsatisfactory. Although this is a defect that is easily corrected, it indicates the fine tuning necessary in a small-scale design [MacCormac, 1983 p 64].

Rick Mather's design for the University of East Anglia, Climatic Research Unit, near to Foster's Sainsbury Centre, is an expression of International Modernism (Fig. 9.13). The interiors have curved white surfaces and a Corb-like playing with levels along with varied sculptural effects of lighting. Mather has definite ideas about the meaning of his own work in the historic context of Modern architecture:

> One of the problems in the perception of Modern architecture might be the popular notion that it is only a Gropius / Harvard School of design. A hundred years from now, all of what we see as diametric approaches will be called 'Late 20th century architecture'.

Mather's commitment to environmental tempering is seen in his earlier design for houses for Khartoum (Fig. 9.14), the volumes are kept simple, but two facades in each case, the north and south, are highly articulated. East and west walls are entirely flush. The interiors, punctuated by round columns, are complex and free-flowing spaces which allow a through-draught.

At the University of East Anglia, Mather strives to avoid the neutralising effect of reaching repetitive offices by way of long corridors. There are a constant series of surprises, such as unexpected views, little places to sit out and frequent changes in lighting. Mather pays homage to the importance of light in his designs in commenting on his work technique:

> I worry and work a lot on the rooms, the natural light..., the contrast of sizes, shapes, dark and light.

There are shafts to funnel natural light right through the top floor to key circulation points below, providing visual connections through all three floors of the building. The windows are individual and sized for each room rather than a generalised band of windows masking all distinction behind. Viewing the facade it is possible to gain an idea of the location and size of the rooms, and the building's internal organisation [Mather, 1986].

The site is unfortunately to the north of a cliff-like row of stratified accommodation blocks. Therefore, a design strategy was developed to counter the resulting blockage of southern sun. An outside room was created in the form of a courtyard and garden, open to the west, to catch the late afternoon sun. In it, there are indoor plants to reinforce indoor/outdoor ambiguities. An illusion of outdoor space is also created in certain places by paving floors that elsewhere are carpeted, by surrounding them with blockwork walls and by providing natural top-light. A low temperature hot water system using excess heat from the computers means the building complex requires little or no additional energy to heat it [Mather, 1986].

Modernist-Organic

The design traditions of Haering, Scharoun, Aalto and Gutbrod are carried forward in the contemporary work of architects such as the German, Guenther Behnisch and the American, Gunnar Birkerts. Most of Behnisch's buildings are based on a varied and impure planning geometry. However, one of the most obvious references to earlier Modernist forms is the extensive glazing with external blinds (Fig. 9.15), reminiscent of Rudolf Schindler's constructivist Lovell beach house (Fig. 9.16). Behnisch's Modernist realisation of a light, airy, layered architecture evokes the forms of Jan Duiker as in Duiker's Zonnestraal Sanatorium (1926) in Hilversum and the open-air school of Amsterdam (1927-28). Duiker's buildings were characterised by slender structures permitting the use of non-loadbearing claddings with large areas of openable glass(Fig. 9.17).

Gunnar Birkerts. One of the largest collections of the glassmaker's art has been installed in the Corning Museum of Glass, New York. Birkerts' design for the museum itself is an impressive demonstration of the properties of glass. The plan of the museum is arranged like the petals of a flower. The extensive use of daylighting makes the displays themselves an internal source of light.

Birkerts' careful studies for the Corning Museum of Glass included research into how light would penetrate the glass curtain wall. A section drawn through the glass wall shows a limited field of vision that cuts off direct rays of the sun and simultaneously reflects distant views inside the museum. Birkerts refers to this detail as a 'periscope.' (Fig. 9.18).

Another building by Birkerts is the Religious Centre in Frankfurt. In it, Birkerts evokes Aalto's forms and use of materials (Fig. 9.19). Birkerts explains his design intentions for this building:

> I am personally interested in finding poetry in building technology and to work with technology to create scale, texture, colour, and other things we cherish that normally come from indigenous materials.... We are too afraid of the imagery of the machine. [Interview with Gunnar Birkerts, Inland Architect January/Feb. 1986.]

Birkerts has seen the rise of Post-Modernism over the last ten years, however he has mixed feelings about this new movement and its relationship to his own work:

> There has been a positive impact, especially the discovery of physical contextualism which was never a movement before. The great discoveries of the modern movement -- freeing supporting structure from the wall, which gave us opportunities to arrange spaces freely, high-rise technology, the elevator, the introduction of daylight -- all this has been lost. Postmodernists are going back to bearing walls, punched openings, compartmentalised spaces. Postmodernism has set us back. Portland is the primary example.

Post-Modernism

Architects who design in the Post-Modernist fashion seem to have rejected the abstraction of logical, technological and functional forms. Instead, they search for cultural and historical references, leading Frankfurt gallery director Heinrich Klotz to describe Post-Modernism as the fall of function, the rise of fiction. [Klotz, 1985] Even though classical structural logic is present in most Post-Modernist designs, only recently, in the work of John Outram, has environmental function emerged as a hopeful, integral part of the Post-Modernist vocabulary.

Outram's architecture virtually stands alone in the Post-Modernist camp in the way in which it demonstrates the potential of synthesising functional requirements and classical shapes. Outram's classical forms are imbued throughout with logical function, imparting an extra layer of meaning to Post-Modernist design. Outram believes that Classicism is necessary because 'when not functioning, Functionalist buildings are just dry and lifeless husks.'

One example of Outram's work is an office remodel for a heating company in Swansey, Kent (Fig. 9.20). The client was a central heating company which wanted a high performance building. The company had bought a 1950s building which was typical of the utilitarian Modernism of its time, mean-spirited with low thermal and acoustic performance and low floor-to-ceiling heights that left no room for ceiling or floor voids.

As re-designed, the new building is a mixture of High-Tech and archaic, exemplified by the propellor solar disc in the gable ends. The discs disguise electric extract fans which are functionally necessary. Outram explains the multivalent meaning of the fans:

> One can read the propellor as a version of the old solar disc borne aloft by a pair of wings. I like the idea of a 'flying pediment.' Historically the pediment is a place that carried the images of the gods. I understand it as the part of the house that exists between the ceiling and the roofs. It is clear that the gods 'lived' in this 'left over' space, like swallows. Of course to me the fan in the corrugated pediment at Swanley is primarily an aeroplane, held aloft by the boosters of the flaming capitals.

Another example of Outram's work is an opulent country residence with environmental double meaning given to many of its structural elements (Fig. 9.22). For part of the structure, he uses sphere-shaped black marble capitals. He explains the meaning of the sphere capitals, which have central holes which contain flues, lights and gutter overflows:

> The volume of the two figures, the cube and the sphere, was one of the obsessions of the ancients. One can read the whole column upwards as the ancient sequence of earth, water, air and fire. The polished black capital is a kind of black and light shadow. It has an eye; the organ of the light that comes to us from the fire of the sun, which is a sphere. In this eye there is an electric light, that lives on

> the energy of the fires that burnt in the sun millions of years ago. In others of the black capitals burn the smoke from the fires of the house. There is no single 'reading' of such ornaments that is 'correct' If there was, it would be propaganda.

Outram's designs prove that Post-Modernists do not have to give up comfort and efficiency in favour of history and romanticism

High-Tech Modernists

In the work of Wright, Aalto, Le Corbusier and Kahn, the architecture of the well-tempered environment is comprised of a totality of design, consisting of formal, spatial and symbolic elements, each of which are faithful to the environmental proposition being made. This tradition is advanced by Late-Modernists who design in a High-Tech style, with its earliest roots in the work of Buckminster Fuller and Konrad Wachsmann.

Architects of the High-Tech genre, such as Norman Foster, Renzo Piano, Richard Rogers and Arata Isozaki, present an uncompromisingly logical image of technology with repetitive, machine-finished elements and strong serial images. Their work symbolizes technology as the hallmark of twentieth-century culture. The building fabric seems to come from functional requirements implicit in structure and mechanical equipment. As Jencks has said, the 'skin and bones' of Mies van der Rohe become the 'bones, arteries and organs' of Richard Rogers. There is an aggressive over-articulation, exaggerated in such a way as if to say that the expression of structure and circulation, of people and hot air, are supremely important; that 'servant' is more important than 'served'.

This is an architecture of grand, public spaces; the High-Tech residential architecture of Hopkins and others has not been a great success. The finishes and furnishings derived from industrial environments are certainly 'high-tech' but the interference with the home's customary image as a 'no-work' place has limited its popularity.

Foster and other High-Tech architects are striving to react to the criticisms of Modern architecture by trying to evolve a more publicly accessible language of form without surrendering the commitment to technology and function. This factor separates the Late- from the Post-Modernists.

Norman Foster. A study of the micro-climatic effects of a large translucent roof in a design for Hammersmith Centre is a good prototype for revealing the working methods and concerns of Foster Associates. The large, central enclosed space is always warmer than outside in winter and of course, protected from wind and rain. In sunny summer weather, the internal temperature is similar to the outdoor shade temperature. The design diagrams generated in Foster's office show how the above forces operate under extreme summer and winter conditions and how the passage of night and day affects the heat transfer process (Fig. 9.22).

The internal environmental services system chosen for the Hammersmith Centre offices attempts to take a long-term view of likely future developments in the technical and energy fields. The offices are provided with heating and cooling by unitary reversible cycle heat pumps. A unitary system such as this permits easy replacement in the event of malfunction or with technically more advanced packages in the future. Cavity floors provide maximum flexibility in the distribution of mechanical and electrical devices and services.

These ideas are carried forward in Foster Associates' Airport Terminal Building design for London's third airport at Stansted. The building is essentially a great transparent shed through which the aircraft and ground transportation will be visible. What makes this possible is the light and elegant roof which floats above the concourse (Fig. 9.23). Daylight is always a Foster preoccupation in a deep plan. The groups of columns which support the roof and in which the services are contained, provide heat insulation, absorb sound and at the same time are transparently carved into so that daylight can be bounced off reflectors and back again to the inside of the ceiling. This gives a diffused sensation of the outside elements in the heart of the building where one does not expect it. The introduction of outside climate to deep interior spaces is repeated in Foster's design for the Hong Kong Bank.

Renzo Piano. It is ironic that much of the work of the 'bowellist' architects, who expose the 'viscera' of their buildings, is chiefly concerned with the display of systems of environmental contral rather than with the quality of interior environment.

In the Pompidou Centre, the inspiration for the design by Piano and Rogers was the idea of flexibility: 'nothing is rigid immutable, the container is flexible, adaptable through the use of 'soft' mechanisms, articulated so that it can be adapted to rapid developments in information systems and communications.'

However, the original design at the Pompidou Centre has not met requirements for viewing works of art. Recently, Gae Aulenti was commissioned to design a reconstruction of the principal gallery space on the fourth floor of Pompidou Centre [Ellis, 1985]. This re-design introduces spatial order and a degree of environmental specificity into the previously flexible, adaptable, 'soft' interior (Fig. 9.24). The original free plan arrangement by Piano and Rogers has been replaced by a highly structured sequence of rooms which takes the major structural bay of the buildings as its principal determinant. The lighting is incorporated in the walls of the new enclosures, rather than on grids in the ceiling structure as before, and by reflecting off ceiling panels, simulates the lighting quality found in many traditional top-lit galleries. Because the partitions stop short of the floor structure above, the air-conditioning plant continues to operate without modification. The transformation is radical and ingenious. But it is ironic that its major achievement is to approximate an approach to museum design which was so emphatically rejected by Piano and Rogers. The aesthetic posture originally assumed by the architects, and its implications for the way in which the internal environment is viewed, has not been borne out after several years' operation.

Piano continues his use of new technology in a subtle and understated way in a recent design for a Houston, Texas Gallery. In formal terms, the building appears to be the opposite of Beaubourg. The scale of the building is modest and the collection is meant to be viewed in daylight. The dominant architectural feature of the gallery is also the solution to interior shading and lighting requirements. For this, Piano has devised an ingenious ferro-cement and ductile iron roof structure composed of light-baffles which act as light filters and as thermal screens. The ferro-cement leaves were manufactured in Britain by specialists in concrete boatbuilding (Fig. 9.25).

Richard Rogers Partnership. The Lloyd's of London building continues a central ideal of the Modern Movement by being very much -- to parapharase Le Corbusier -- 'a machine for working in'. Set in the financial district of the City of London, Lloyd's has also been described as a Neo-Gothic 'machine for making money'. Peter Cook has described it as being 'fundamentally the Louis Kahn formula of served space and service tubes around it — [allied]...with an extruded British greenhouse'(Fig. 9.26).

The Lloyd's building is more mature than its Parisian predecessor by Piano and Rogers. The external duct-work expresses the logic of services with more consistency and clarity than in Centre Pompidou. Exposed air-conditioning ducts have become one of the characteristic motifs of High-Tech architecture and of the architecture of Richard Rogers in particular. The architects learnt from Beaubourg, where the metal ducts were painted in bright colours. At Lloyd's, the metal components are self-finished to reduce maintenance, so the ductwork, drainage, water supply, electrics and communications services are all encased in stainless steel.

It is a deep-plan building, lit from an internal vertical atrium, which makes a considerable show of its construction and the technological apparatus of climatic control. In fact, the idea of the moated castle was one of Rogers' acknowledged sources for the basic parti of the plan, and the building has been described as 'introverted'. The glass cladding is more translucent than transparent, and the building does not reach out with pleasant views nor give those within the chance to experience the cycles of the day and seasons.

Some of the technological problems posed by the glass were previously encountered by Le Corbusier. He conceived of the 'mur neutralisant' (see Chapter 6), and developed this idea in conjunction with the St. Gobain glass company. As in most buildings of this type, the glass cladding must meet several technical performance criteria. It has to play the correct role in the overall thermal balance of the building in summer and winter. It has to provide outlook. It has to transmit as much light as possible, whilst reducing the brightness of the sky and diffusing the incoming light. It should reduce solar heat gain. It should ensure that people who are close to the glass are not at a different temperature compared to those in the interior of the space. It should not reflect the interior at night. This set of problems has been solved by using three layers of glass for the design of Lloyd's. There are three layers of glass. The outer two are sealed double glazing with a low emissivity layer on the outside of the inner pane which reduces the heat loss of the building so that the normal heat gain inside can meet most of the heat needed during cold weather. The inner layer is a dimpled translucent glass.

The dimpled glass of Lloyd's makes reference to the Maison de Verre of the heroic Modern Movement, whose glass block facade created 'walls of light' when illuminated externally or internally. One of the aversions to clear glass walls is based on the fact that, while clear glass walls look fine in the daytime, at night they become mere areas of blackness, reflecting the interior. With the special glass, the walls become shimmering screens, at least in theory. The glass transmits only 10 per cent of incident light and even less incident energy. In this way the glass walls transmit some light and also perform nearly as well as opaque walls. For those who prefer to be able to see out, a band of clear glazing is provided at standing height in the Room and at sitting height in the lettable offices on the upper floors. The Room is the central trading area at the lower level of the atrium.

The heating and cooling scheme is made possible by circulating water which is used by small heat pumps in the floor space for either heating or cooling. If heating is needed, the circulating water loop is used as a heat source. If cooling is needed, the circulating water is used as a heat sink, in which case the heat is carried someplace else in the building where it is needed, or rejected to the outdoor air.

Warm air collected at ceiling level is extracted down between the inner glass skin and the double glazing so that the inner glass skin is near to room temperature and virtually no heat is gained or lost from inside to outside. The cavity of the glass cladding serves as a plenum for carrying extract air from ceiling void down to the floor level (Fig. 9.27).

The light fittings are surrounded by spun aluminium ceiling discs which are centered within each square bay of the exposed ceiling grid. Remarkably, the discs are not designed to be reflectors and this is emphasised by their black surface. This has led to the observation that the ceiling, as well as the sea of blue carpet, obscure glass and the deep atrium, gives the light in the Room a strange underwater quality.

Capsule- and mega-spaces. A new segment of the accommodations industry has developed around cheap international jet travel. It is making use of a building type known in Japan since the early 1970's, the 'capsule hotel.' In Japan, the capsules are lined up along an aisle, two high. Each capsule is roughly 5 feet wide, 10 feet long and 6 feet high. Early examples are Kisho Kurokawa's Nakagin Apartment Tower, Tokyo, 1972, and Tatsuhiko Nakajima and Gaus, Kibogaoka Youth Castle, 1973 (Fig. 9.28).

In the Nakagin Apartments, 140 rooms are suspended from two concrete cores. These steel boxes are modified shipping containers which contain bathrooms, stereo-tape decks, calculators and other amenities for the businessman or bachelor. It is made up of asymmetrical and syncopated clusters of capsules with an air of individualism and, in the Zen tradition, imperfection.

The form of capsule hotels is related to designs for living and travelling in space which have been around for some time. Architects have been involved in the design of the space capsules from the outset.

Raymond Loewy was responsible for some of the early designs of NASA Skylab and early space station designs of the 1960s and 1970s (Fig. 9.29.). Futurist architect Jan Kaplicky proposes a literal terrestrial use of lunar-landing forms, called 'Peanut' (Fig. 9.30.). This and other similar solutions advocate self-contained environmental control systems which permit the independence only hinted at in American recreational vehicles.

The space capsules which have made their appearance in the West are slightly more spacious than the Japanese prototype. At Los Angeles International Airport, a new mini-hotel offers accommodation 'by the hour or by the shower'. The Los Angeles 'Skytel' has a rental rate of 70 times a day for just 13 rooms. The same concept is successful in Europe, where it is known as the 'Flytel' at the Copenhagen Airport. Looking like futuristic, shiny aluminium railway carriages, the Skytel offers all the comforts of its counterpart hotels in the city. The owner of the L.A. Skytel explains the imagery:

> Actually, the intended effect is more that of an airplane fuselage. Thus, passengers who are still carrying the feeling of being on a jetliner can adapt comfortably to their new surroundings.'

Each of the 13 rose-coloured, air-conditioned and sound-proofed rooms measures 2 m by 4 m. Each room contains a single-size bed and bedding, a closet, a table hinged to the wall, an elevated 10 inch colour TV set with remote control, an overhead reading light and smoke detector, a multi-band clock radio receiver, a telephone usable with credit cards, and a socket available for travelers carrying personal computers.

The adjoining bathroom has a hair dryer mounted in the wall, a make-up mirror with 10 bulbs, a commode, sink and stall shower with Shower Massage unit. Awaiting the guest are a disposable toothbrush with toothpaste, envelope of shampoo, envelope of clothing spot remover, disposable razor and blades, shave cream, eye make-up remover, shoe cleaning cloth, bar of soap, box of Kleenex, face cloth and towel.

A guest pays $7.50 for a half-hour shower (plus 11% for room tax), $15 for an hour's use of the room, the hourly scale continuing until it becomes $45 for eight hours.

As with most new endeavours, there were adjustments. 'When we first opened in September, we charged by the minute -- 25 cents per minute,' Panish said. 'But people became confused. They weren't used to that in a hotel. So after two days, we switched to the hourly rate.'

Mega-spaces: Parc de la Villette. The tradition of mammoth exhibition spaces reaches a zenith in the nineteenth century with the construction of the Crystal Palace and continues into the middle of the twentieth century with the realisation of the Centre Beaubourg in Paris. The latest monument of this type is four times the volume of Beaubourg. It is the Parc de la Villette, France's new Museum of Science and Industry, described as the biggest and most expensive scientific museum on this planet.

The building is a demonstration of technical prowess, rising from a sunken lake. It contains a vast, top-lit foyer, stretching to the full height of the building, achieved by carving away floors, and has huge glazed bays on the south elevation. The spectacular toplights and glazed bays follow detailed designs by Rice Francis Ritchie and are appropriate to a modern museum of science, as they represent a considerable feat in the highly skilled and innovatory use of (entirely French) materials (Fig. 9.31).

The two great circular toplights are each 17 m in diameter. They are supported by a lightweight structure suspended from six points at the perimeter of a rectangular opening in the roof. Weather-proofing is achieved by the insulated and ventilated, white, twin-skinned Teflon tent structure. The glazed toplights, with integral multiple computer-controlled mirror reflection systems, revolve mechanically to optimise daylighting conditions 40 m lower down in the foyer. Seen from a distance, this lightweight roof structure covering 2200 sq. m. is dwarfed by the sheer scale and bulk of the museum building, but when observed from within the foyer, the true nature of this achievement can be appreciated.

One hundred and thirty years after the Crystal Palace, Rice Francis Ritchie has created a flush but flexible skin of glass on a stainless steel structure subdivided into 8m x 8m modules, each containing 16 2m x 2m glass sheets. Sixty four sq. m. areas, each composed of 16 2m x 2m glass sheets are held in place without intermediate framing. The edges of the glass are simply abutted one to the next. The resulting glazing is calculated to resist three times normal wind loading and load transfers if the glass breaks.

Is it possible that this building is one step towards fulfilling the promise held out by Fuller and others of changing the micro-climate on a grand scale through encasing large areas of the planet in glass and lightweight structure?

With this glimpse of the future of an architecture of the well-tempered environment, the question remains of the relation between art and science in determining the order and form of architectural space.

Summary

As we move closer to a cybernetic, rationally designed environment, the way in which designers use knowledge about climate and available materials in order to create comfort still draws on both imagination — art — and a method for testing ideas — science. Is the resulting design of the well-tempered environment a scientific or an artistic expression, or both?

On one side, T. S. Kuhn and his colleagues in the history of science generally deny the similarity of art to science. For Kuhn, an admission that art has value as knowledge or truth would disturb the order of philosophy as it has existed since Descartes and Bacon first laid the empirical basis for natural philosophy. If art is a form of knowledge, then one could reasonably expect poetry, music and lyrical designs to have knowledge or truth value as well.

The key to Kuhn's position stems from his description of scientific revolutions which occur as a result of 'paradigm shifts' that he has likened to Gestalt shifts [Kuhn, 1977, p.342]. Such paradigm shifts are associated with major upheavals in science, such as the Copernican revolution or Einstein's relativity theory, but in almost any discovery.

Paintings are the problem solving models or paradigms of art. Likewise, the paradigms of architecture are buildings and the drawings and models of buildings. Kuhn argues that these paradigms of art and architecture are not truly analogous to those of science. The paradigms of scientists are not the products of their work, i.e., their research findings, articles or books, as they seem to be for the architect, but rather, the methods of problem solving.

Kuhn believes that once a paradigm in science is abandoned, it is abandoned forever. When the Copernican paradigm replaced the Ptolemaic, for example, the Ptolemaic was banished from the textbooks; scientists either adopted the Copernican system or were ostracised from science. As Kuhn states the process, 'to change style within a scientific field is to confess that one's earlier products and that of one's masters are wrong.' [Kuhn, 1977, p.348]

However, far from 'destroying its past' as Kuhn asserts, science is actually quite selective in what it retains of its past, building upon that which has been most useful. The solution of scientific problems becomes a form of cumulative puzzle solving. It is interesting to note that textbooks of physics today still present facsimiles of Galileo's insights into motion, Newton's laws, and Maxwell's electrodynamics. Neither Planck's nor Einstein's work relegated Maxwell, Newton, or Galileo to the dustbin of history. Chapters discussing Planck and Einstein have been placed at the end of modern textbooks of physics.

Artists and architects, like scientists, learn in a progressive manner from the collective successes and failures in the profession. On this matter E.H. Gombrich has written:

> I am absolutely convinced of the fact that ... art, like science, is cumulative in the sense that one generation learns from the other but modifies and corrects what the previous generation has done.' [Gombrich, 1983, p. 222]

In architecture, the classical inventions and traditions in environmental tempering have not disappeared in the ruins of antiquity. The buildings and monuments of the past have exerted an influence on the work of Wright, Le Corbusier, Aalto and Kahn. To paraphrase Le Corbusier, Modern architecture has been built on the lessons of the past.

Scientists no longer work on problems posed by Galileo and Newton, whereas the work of Einstein and Schrodinger still poses dozens of important problems for which solutions have not yet been found. A scientist's reputation is made by solving unsolved problems, just as a designer's reputation is made by resolving stylistic exigencies. Both the scientist and the architect naturally focus their attention on areas of research where problems which seem amenable to solution exist.

Whereas Kuhn and C.P. Snow claim that science and art have become increasingly different during the past 150 years, it appears to be exactly the opposite. The methods of architectural design are becoming more and more like the methods of science. A full discussion of the origin of these likenesses has been written in a comprehensive volume by C.H. Waddington. This is the conclusion not of an art historian but of one of the important biologists of the twentieth century. His analysis begins with Kuhn's paradigm theory and ends with the argument that art and science, at the level of creative process, are virtually indistinguishable.

Christopher Alexander, who believes that architects' activities border on scientific discovery, represents the opposing view to Kuhn's. Alexander maintains that art is a science and science an art and the differences blur into insignificance. The scientist and the artist explore new ways of perceiving and of controlling nature by using similar methods. The difference between the intellectual and physical products of the designer and the physicist are no greater than those between the physicist and the biologist, or between the painter and the sculptor.

The equivalent to the scientific experiment in architecture would be the esquisse, the sketch, which shows the process of deductive reasoning which results in architectural design (Fig. 9.32). The scale model is another research method for architects which is used to study aesthetic questions in the disposition of shape, mass, scale and and the play of light.

For Wright, Aalto, Le Corbusier, and Kahn, the metaphor is the currency of artistic imagination; the maquette and the esquisse are methods of architectural research. The designer proposes hypothetical architectural solutions. The validity of these ideas is tested by means of models and drawings. Both imagination and a method for testing ideas are necessary for the unity of the design. In Le Corbusier's words:

The architect should be a man with a logical mind: an enemy of love of the plastic effect; a man of science but also with a heart, an artist and a scholar. [Jencks, 1973A, p 25.]

Louis Kahn represents the design solution for the Richards Medical Laboratory in the form of a partly abstracted scale model of the structural skeleton and mechanical and service towers. This model is a test of metaphor; as such it represents both science and art. As a model, it allows visualisation and evaluation of the relative efficiency of the structure and the mechanical system; as a metaphor, it conveys Kahn's concept of integration.

Just as the design of environmental systems is a microcosm of architectural design, architecture is a microcosm of society. Architectural masterworks are representatives of whole systems of thought and feeling. When architects talk amongst themselves, they invariably exchange the names of buildings as code words for the design principles that interest them. "Robie House", "Ronchamp", "Pompidou Centre"; each brings to mind a particular approach in applying technology to solve environmental problems. The synthesis of art and science in architectural masterworks appears to lessen the distinction between science and art in architecture. In the best examples, art and science are synthesised in such a way that both are expressed as one voice.

In environmental tempering, there is in fact a group of scientifically trained individuals who do nothing but work in old scientific traditions: today's <u>fumistes</u> are the building services engineers, whose job is to apply existing problem solutions to the design of new apparatus. The engineer is not properly considered a scientist. Likewise, an artist or an architect might be defined as anyone who can use the tools of the trade. But it is useful to distinguish, as in science, between individuals who use those tools as previous traditions have used them and those who attempt to invent new tools, to interpret new problems, and synthesise new problem solutions.

Only the latter are truly artists, the former being the technicians and engineers of art and architecture.

It would seem reasonable to conclude that if architects selectively reject earlier traditions of architecture, it is for the same reasons that scientists reject earlier traditions of science: the old problems are solved, new ones await. Certainly an architect could choose to draw and design like Charles Rennie Mackintosh or Frank Lloyd Wright, just as a scientist could choose to perform experiments on falling bodies similar to those conducted by Galileo. Beginning students in each subject often do exactly these things. Both exercises yield results: beautiful designs and valid data. But designing like Frank Lloyd Wright tells us no more about perception and solves no new problems in the flow of space and the use of light than Wright already did, just as more data on falling bodies reveal nothing new about the nature of motion. Experience has shown that architectural practices based on mimicry of past traditions do not tend to be vigorously successful. To be successful, the architect, like the scientist, must introduce into his discipline new methods, new perceptions, or new phenomena that raise new problems for colleagues to address.

The artists and architects who change the history of their field are those who, like Picasso, Frank Lloyd Wright or Le Corbusier, make conceptual leaps in addressing problems of how to see or experience art or architectural space in new ways. For them, the painting or the building is not an end in itself, but rather a scientific or artistic experiment in perception, and in the application of new rules of environmental tempering, the concept of space (cubism) or the flow of space (prairie architecture) or the application of technology (pan de verre).

The painter, Georges Seurat, one of the first to apply the scientific theory of colour mixing and contrast to painting, was not painting simply to record what he saw. He was attempting to invent a theory of art:

> If, with the experience of art, I have been able to find scientifically the law of pictorial colour, can I not discover an equally logical, scientific, and pictorial system to compose harmoniously the lines of a picture just as I can compose its colour? [Homer]

Most architecture of the early twentieth century must be perceived as attempts to experiment with structure, materials, decoration, light, colour, social conventions and perceptual convention.

Unfortunately, neither mode of thought has an adequate methodology to answer questions of value judgment. Science is accused of being technocratic when dominated by methods which lack humanistic values. Art is accused of aestheticism when it generates forms without content. However, arguments of pragmatics or aesthetics alone do not resolve the nagging questions of economics, environmental performance, energy efficiency and the provision of comfort and delight.

The Cultural Role. The slow, steady evolution of a vernacular, unconscious architecture of the well-tempered environment has inspired and validated the contrivances of architectural style. Given a climate, available materials and technology, the final element that moulds the form of a dwelling the vision that people have of an ideal life. Despite meagre resources, primitive people have designed dwellings that successfully meet the severest climate problems. These simple shelters sometimes outperform the energy-consuming structures of present-day architects.

Elements of folk-architecture which inspire formal architectural designs are seen in the concept, function and form of the fireplace and hearth. From its purely folk origins, the hearth gradually evolved into the powerful environmental symbol of domesticity put to purposeful use by architects of nineteenth century England and by Modern architects such as Frank Lloyd Wright. The theory of expression of function can be traced from Viollet-le-Duc, who demanded the expression of each of the elements of a building, especially its structure, to Louis Sullivan, who insisted that the form of a building can be derived from a full knowledge of the purpose it is to serve. In the 1930s, the logical extension of this line of reasoning was that the form which most closely follows function, for example, ships and aeroplanes, is the most beautiful.

In Britain, the philosophical vision leading to the environmental functionalism of High-Tech architecture predates the twentieth century constructional fidelity of the Arts and Crafts and the structural rationalism of Lasdun and Arup Associates. This philosophy is seen in the striving of High-Tech for an authenticity in its making which must be clearly seen. The other debt of High-Tech architecture is owed to the nineteenth century British engineering tradition of creating new spatial experiences in steel and glass.

Western science may be able to simulate and measure environmental forces with great accuracy and to invent all manner of machinery with which to modify the interior climate. But Western technology -- especially modern American technology -- too often responds with the mass production of a handful of quite clumsy stereotypes which answer only the immediate demands of the marketplace. Architecture can still be greatly enriched aesthetically as well as operationally by a sober analysis of tradition.

<u>Borrowed Order and Form.</u> Wright reached deeply into western cultural values to give shape to a hearth, whose primary function of providing heat and light became one of almost pure symbolism. The logical conclusion of

this evolution resulted in the simultaneous use of a hidden source of heat under the floor, along with the symbolic open hearth at the center of the house.

In an analogous way, Modernists, the fantasists and visionaries of the 1960s, and High-Tech stylists have taken architectural form, both literal and symbolic, from other technologies. To them, the aeroplane, the ship, the automobile, and the refinery serve as metaphorical sources for machines à habiter. These stylistic influences are most strongly seen in Metabolist (bowellist) and High-Tech designs, where the environmental control system appears as a sort of badge of honour, signifying entry into the future, the 21st century, the space age.

There has been inevitable disappointment when those forms in fact have not offered significant environmental and functional improvements over what the older technology afforded. It is simply 'older technology dressed up in borrowed clothes' and its weakness as a generator of style is revealed with the passage of time.

In modern times, mechanical and electrical systems extend the possibilities and make the task of providing comfort nominally easier for the architect. Today's technology corrects or covers over the shortcomings in environmental performance which may pop up in climatically inappropriate architecture. It is thus easier for the architect to impose stylistic imperatives in hostile climates. Even though perfect control of the environment has become possible, in many cases the architect finds it difficult to remain in command of the totality of a design which needs complex mechanical and electrical systems for its operation.

Closer to a Definition. Inductive reasoning tells us that if the specific case is true, then the argument holds for the general. We have shown that the introduction of architectural elements related to controlling the environment, i.e. the chimney, the fireplace, the inglenook, the window, ventilation systems, are all capable of having a profound architectonic effect on the form of buildings. Environmental control systems can change the organisation and the structural and rational qualities of architecture. In the best examples, the elements of environmental tempering have served to relate the parts of a building to each other and to the whole. In addition, it has been shown how these shapes and forms carry cultural and symbolic meaning. The refinement of the genre has resulted in poetic expressions of architecture of the well-tempered environment, in which environmental tempering imposes upon the lyric design an ordered sequence, an organic unity and a clarity of purpose.

One approach to a definition of the architecture of the well-tempered environment is to study its extreme forms. An extreme of environmental tempering in American architecture is the house of the American architect Philip Johnson, at New Canaan, Connecticut, cited not because it is unique, but because it is among the first to achieve its effect. Banham's description of American domestic architecture as 'a brick chimney with a shack leaning against it' is recalled by Johnson's glass house, which consists essentially of two elements, a heated brick floor slab and a standing unit which is a chimney / fireplace on one side and a bathroom on the other.

To pursue the notion of extremes a bit further, interior space in Johnson's house does not stop at the glass; the terrace, even the trees beyond, are visually part of the living space in winter. The interior space becomes physically and operationally joined with the exterior in summer when the four doors are open. If Wright discovered how to 'break the box', Johnson simply removed the sides of the box entirely. The 'house' becomes little more than a service core set in infinite space. Johnson describes how he regulates the environmental tempering system:

> When it gets cold I have to move toward the fire, and when it gets too hot I just move away.

When Groff Conklin wrote:

> a house is nothing but a hollow shell... a shell is all a house or any structure in which human beings live and work, really is. And most shells in nature are extraordinarily inefficient barriers to cold and heat...

he was summing up a general American view of artificial control of the environment, carried to its extreme by Johnson and those who followed. This attitude harkens back to the nature of a 'cowboy' society which does not have a tradition of thehusbanding of scarce fuel resources, and where the wasting of energy and materials is justified by the boldness of the statement and the environmental effects achieved. In other cultures, such architectural statements might be considered at best an example of engineering overkill, and at worst tasteless. European architecture offers examples which achieve dramatic environmental effects, considering the greater efficiency of means.

The question of cause and effect in the relationship of environmental tempering to the shape of architecture is vexing. In specific instances, architecture is purposefully shaped by the need for environmental systems. Kahn's Richards Memorial Laboratories come to mind when one thinks of the massing of the building and the disposition of major volumes for the handling of air. In other examples, it could just as easily be said that the environmental control systems receive their shape from the architecture. The point is that in the best examples, the well-tempered environment inhabits the architecture as an integral element, giving and receiving shape as the case may be.

With the passing of the Modern masters, the architectonic aspects of environmental tempering have not disappeared, but have continued to grow in richness and formal possibilities. In the 1980s, Late-Modernists have brought forward the tradition in a way that haunts the critics of Modernism. Today, vital sources of Modernist style continue to inspire outstanding functional designs set firmly in the times.

The short-lived energy conscious architecture of the late 1970s has spawned a series of devices that have seen some application in mainstream American architecture; 'Trombe walls', 'sunspaces' and 'lightshelves' are morphemes which define a species of modern vernacular characterised by almost pure environmental function.

Proof of the relationship of environmental tempering to the shape of architecture — if it is possible to give the proof to poetry — exists in the masterworks of Wright, Le Corbusier, Aalto, Kahn and others. Theirs is a body of work around the theme of the well-tempered environment which transcends conventional formal and stylistic boundaries. Contemporary architects still find architectural unity and spatial delight derived from adaptation to climate and the provision of comfort. Environmental tempering will have architectonic power for future architects as long as shape is derived from pure function.

ILLUSTRATIONS

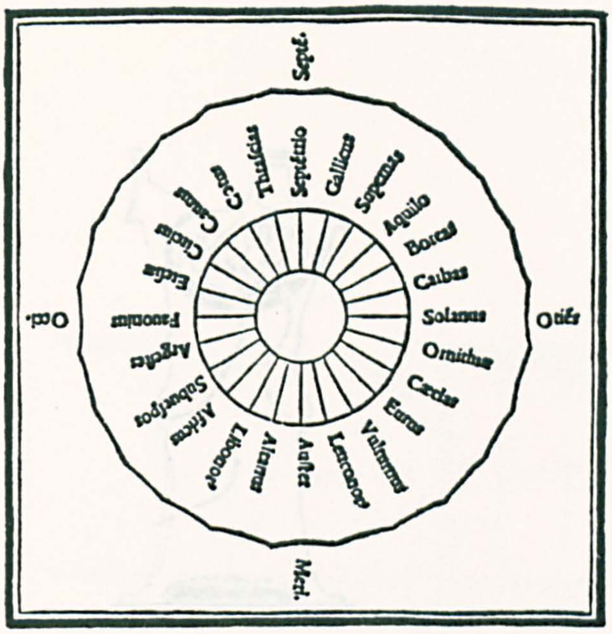


Fig. 1.1 Diagram of the Winds, according to a classification scheme by Aristotle. This version appeared in the edition of Vitruvius by Fra Giocondo, Venice 1511.

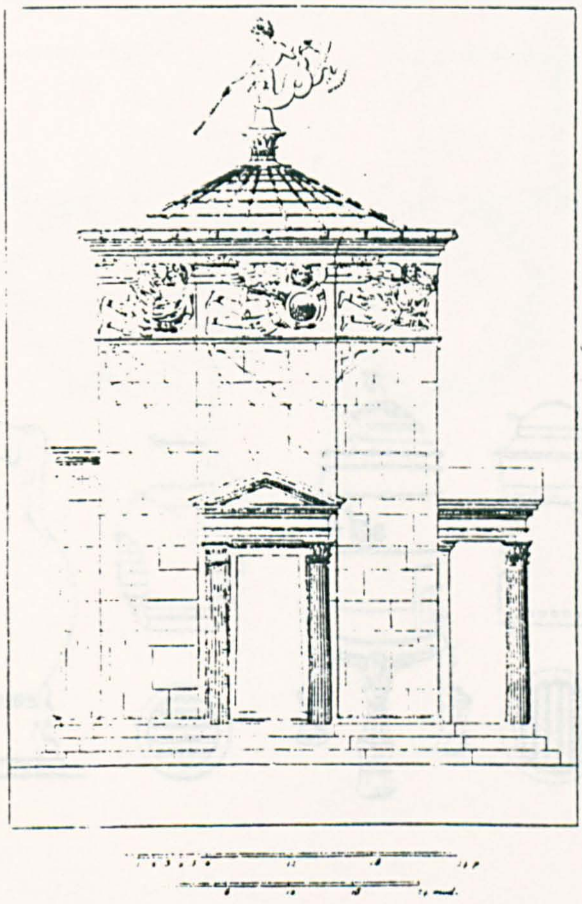


Fig. 1.2. Tower of the Winds, Athens, 2nd century B C. The neptune figure on top rotated and pointed to the appropriate wind. Traces of the sundials can be seen on each facade. Inside there was also a clepsydra or water clock for telling time.

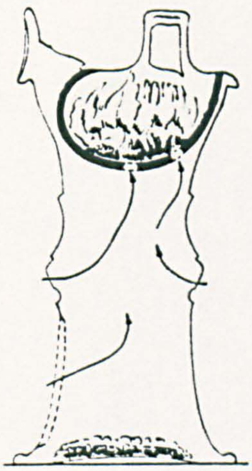


Fig. 1.3. Ancient ceramic portable stove with elevated fire compartment, an ash pit, and provisions for induced draught.

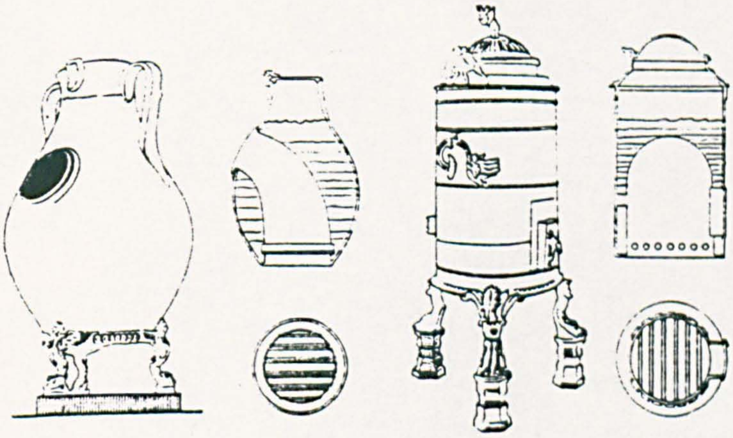


Fig. 1.4. Roman vessels for heating water, found at Pompeii.

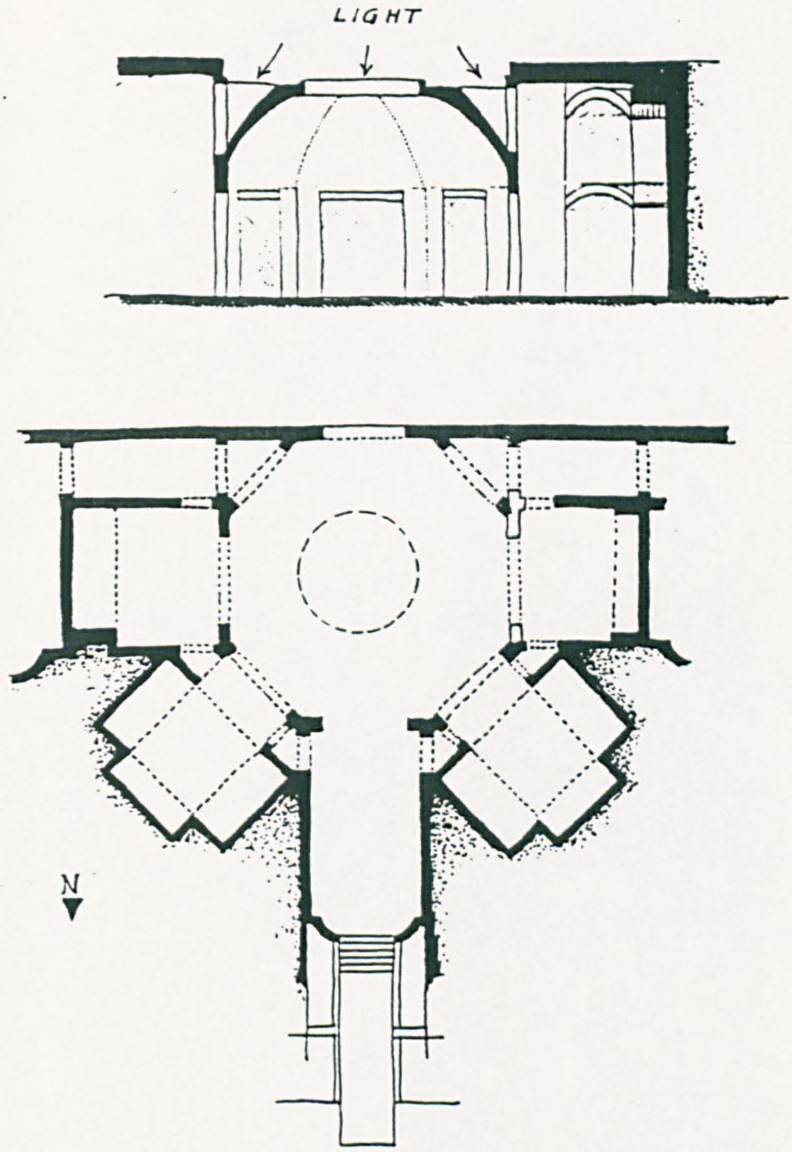


Fig. 1.5. Nero's Golden House, Rome (A.D. 64-68), Section and Plan.

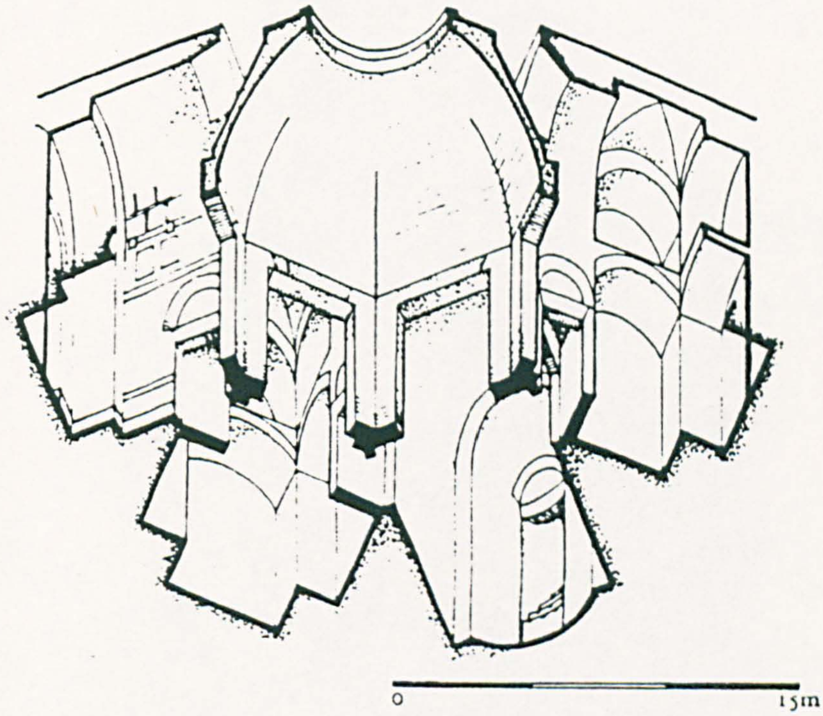


Fig. 1.6. Nero's Golden House, Rome (A.D. 64-68), Octagonal Hall with fountain, axonometric view from below.

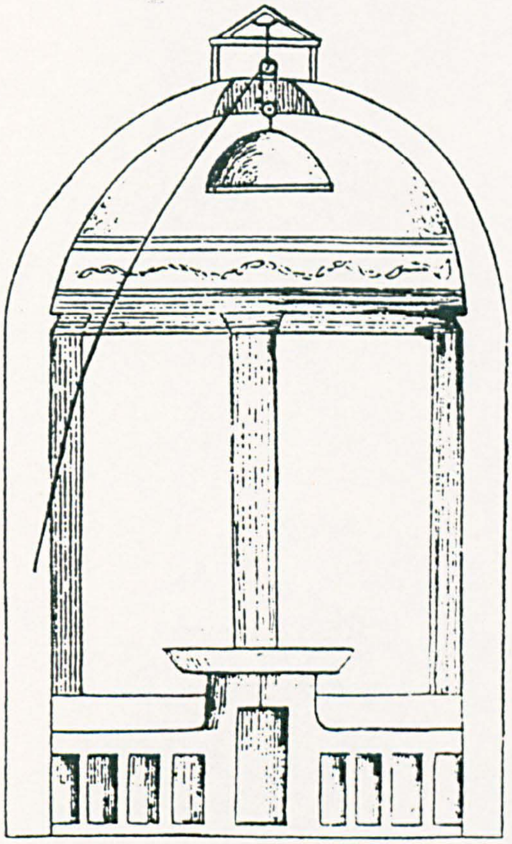


Fig. 1.7. The clipeus, a device used for regulating heat, ventilation and light in the bath. It consisted of a hemispherical metal plate suspended by chains under an opening in the dome of the ceiling at the cirular end of the caldarium; by raising or lowering the plate, the amount of cold air permitted to enter was controlled.

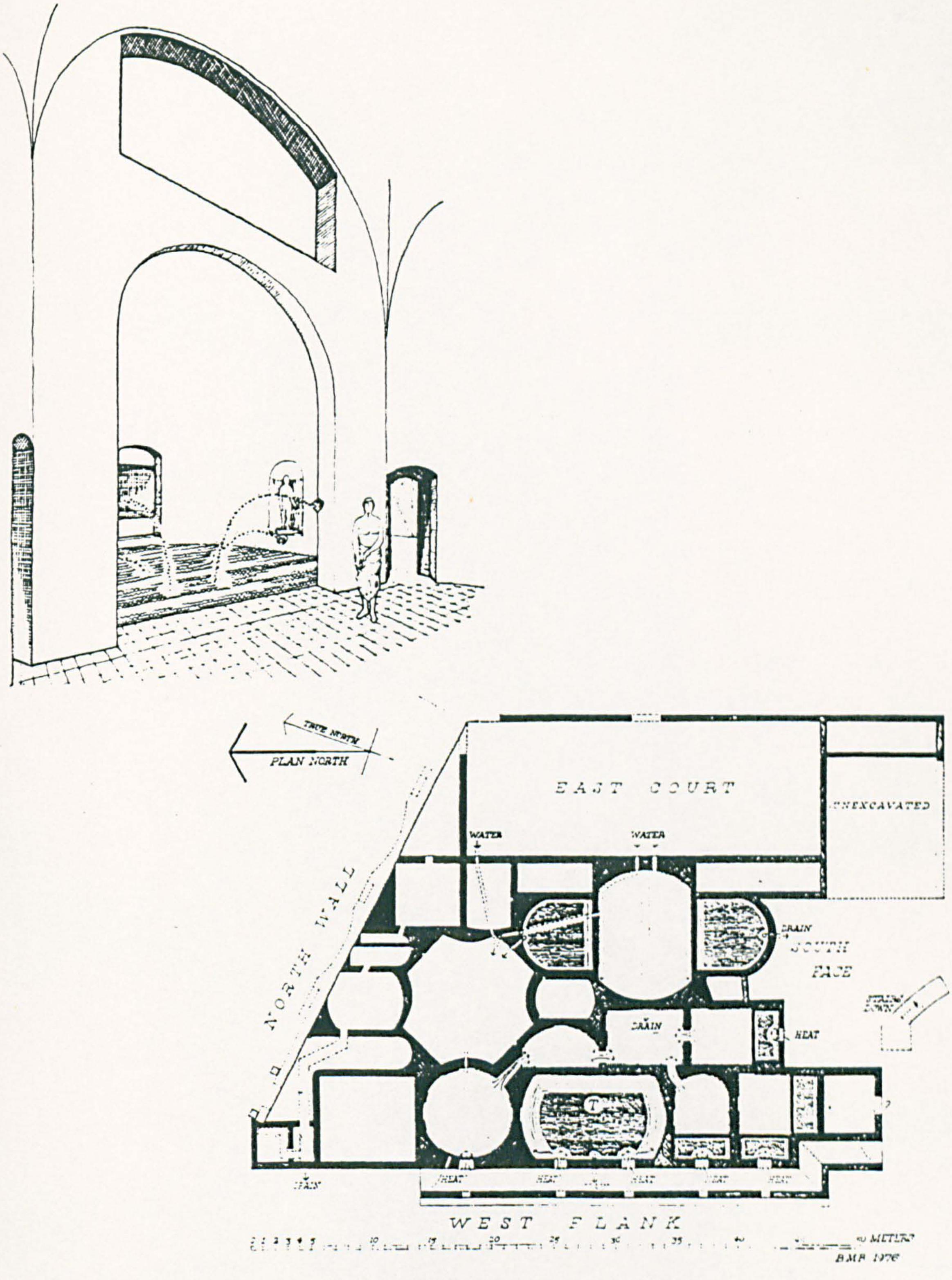


Fig. 1.8. Private baths at Hadrian's Villa at Tivoli (c A.D. 120) which demonstrate some of the most unusual architectural arrangements of the time.

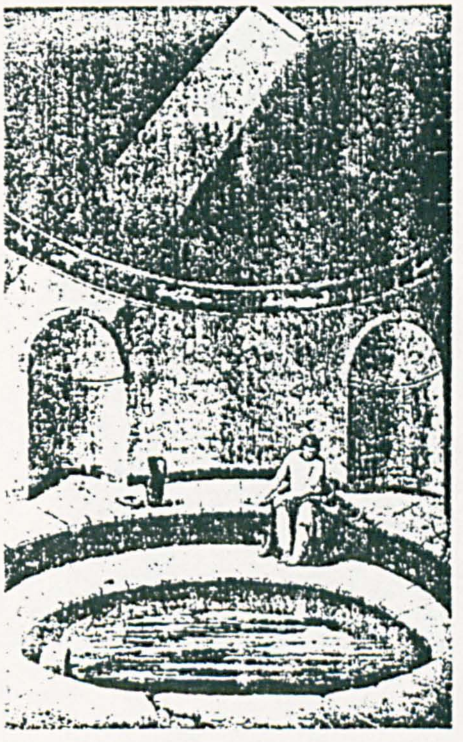


Fig. 1.9. Interior of an early Roman bath modelled after the Greek laconicum with a single oculus in the domed roof for the passage of light and air.

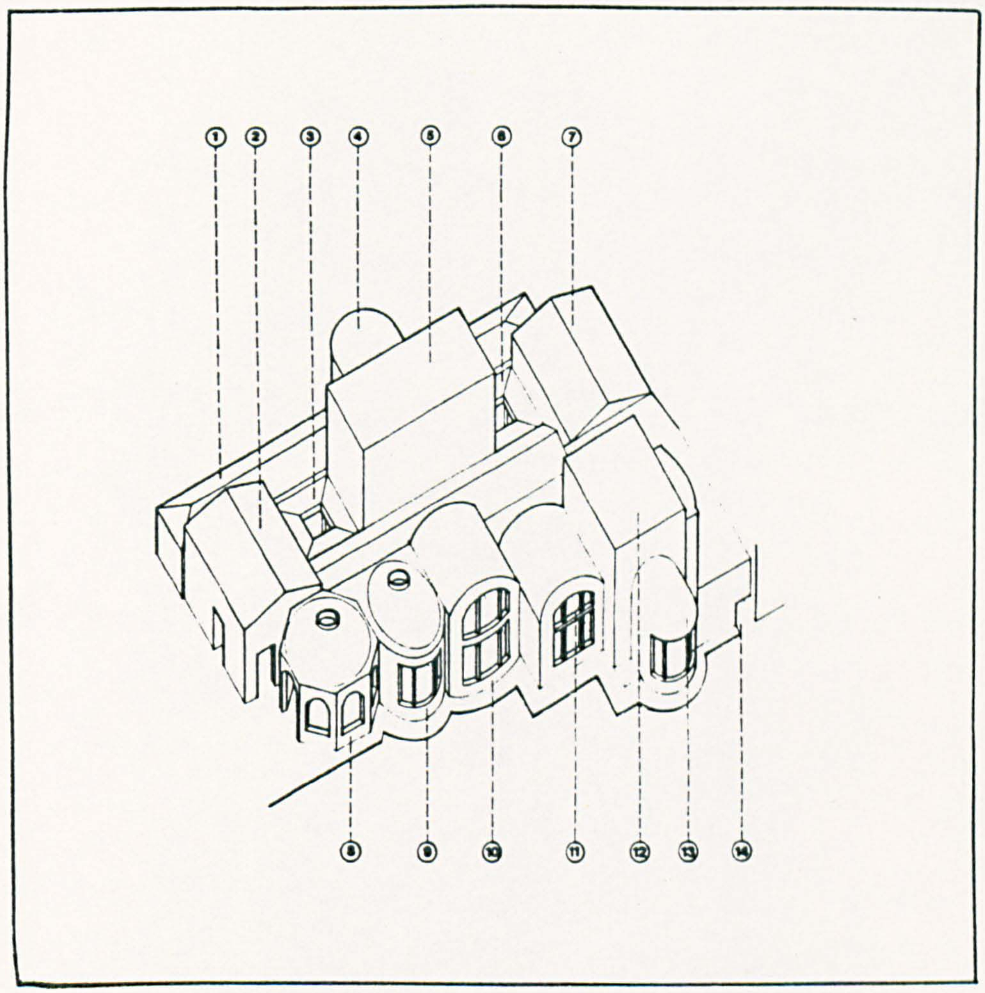
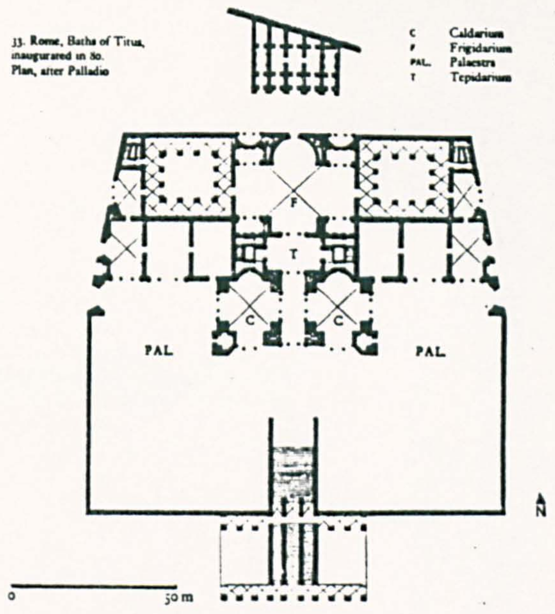


Fig. 1.10. Baths of Ostia Antica (2nd c. B.C.); diagrammatic layout of major building forms:

1. Entrance
2. Dressing room (apodyterium)
3. lounging court
4. cold pool plunge
5. cold room (frigidarium)
6. lounging court
7. apodyterium
8. sun room (heliocaminus) with prominent, south-facing glazed apertures
9. sweat room (laconicum) based on original prototype
10. warm room (tepidarium)
11. warm room
12. hot room (caldarium)
13. pool
14. entrance to exercise grounds (palaestrum)



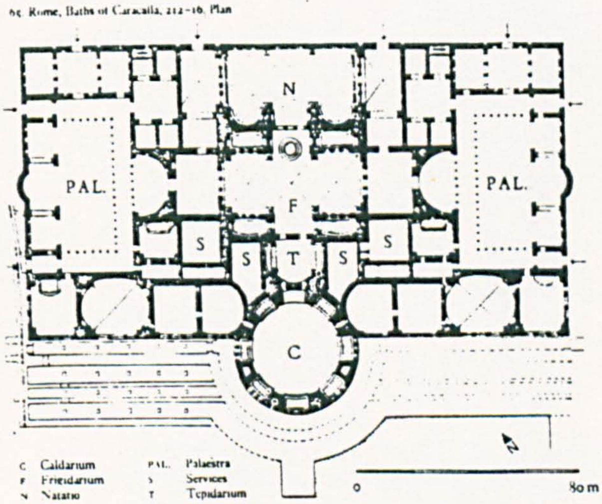


Fig. 1.11. Baths of Titus, Rome, inaugurated in 80 A.D., plan (top) and Baths of Caracalla, Rome (212-216), plan (bottom).

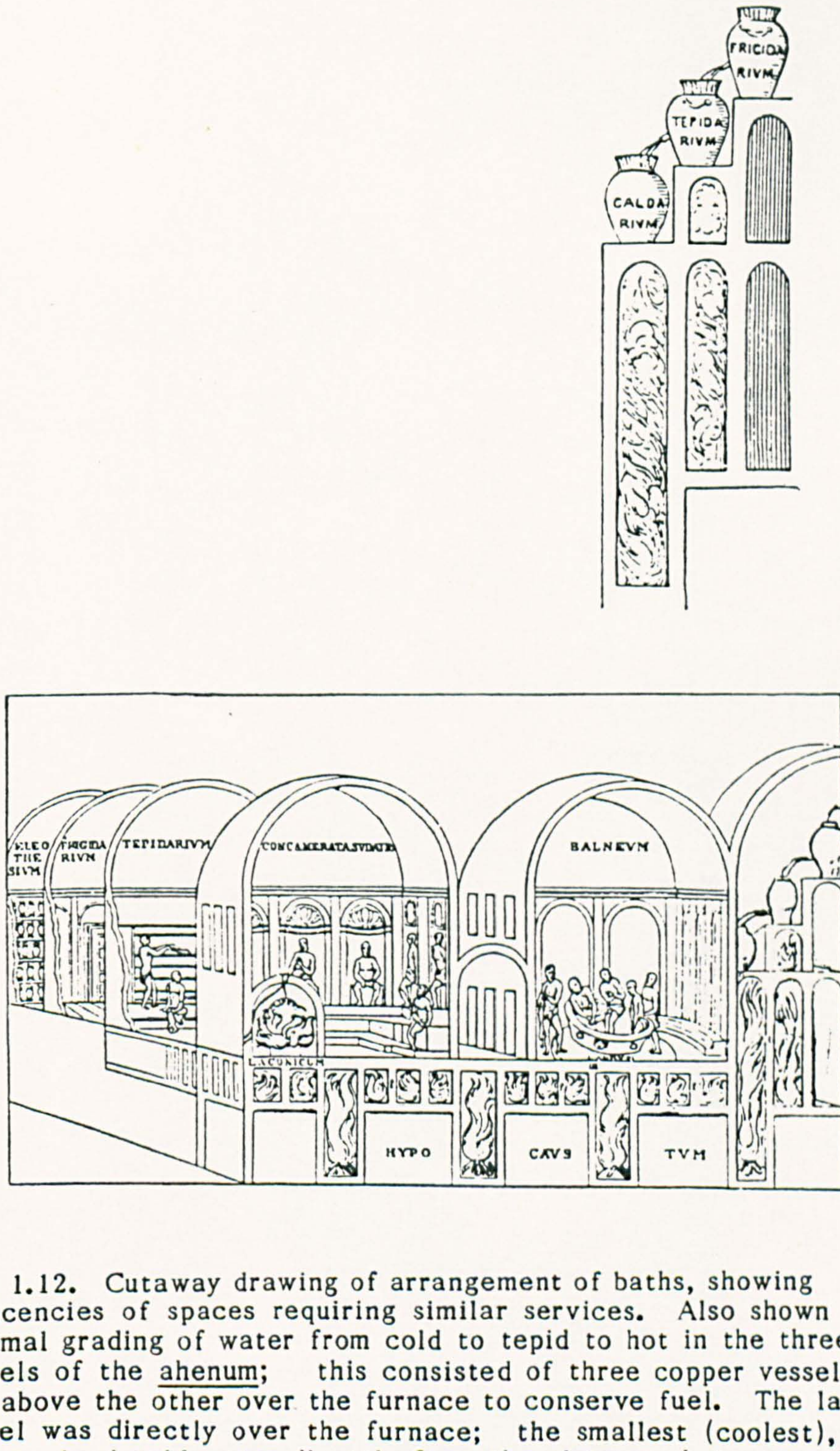


Fig. 1.12. Cutaway drawing of arrangement of baths, showing adjacencies of spaces requiring similar services. Also shown is the thermal grading of water from cold to tepid to hot in the three copper vessels of the <u>ahenum</u>; this consisted of three copper vessels placed one above the other over the furnace to conserve fuel. The largest vessel was directly over the furnace; the smallest (coolest), at the top received cold water directly from the cistern; hot water drawn from the lowest vessel was replaced by water from the middle one, which had already acquired a certain amount of heat.

Fig. 1.13. Hans Holbein the younger, The Ambassadors (1533); detail, showing instruments used by architects to calculate the geometry of the sun's position in relation to buildings.

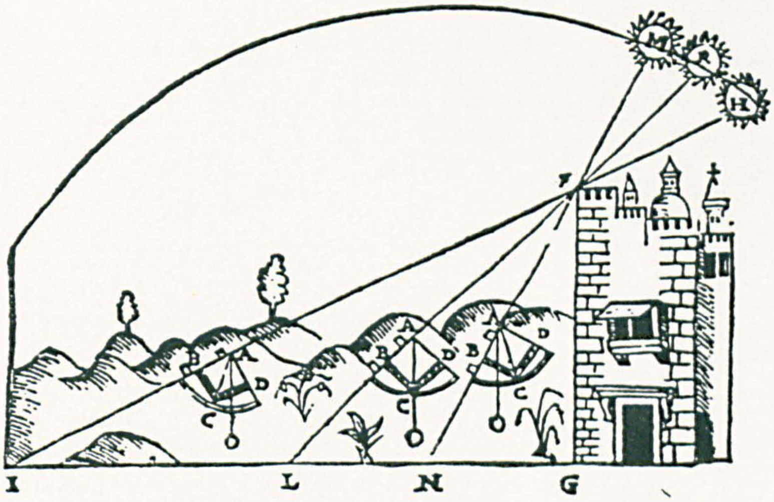


Fig. 1.14. Woodcut of 16th century surveying instruments and their use in relationship to the sun and to buildings, from Cosimo Bartoli, *Del modo di misurare le distantie, le superficie, i corpi, le piante, la provincie & tutte le altre cose terrene*, Venice, Francesco Franceschi, 1564.

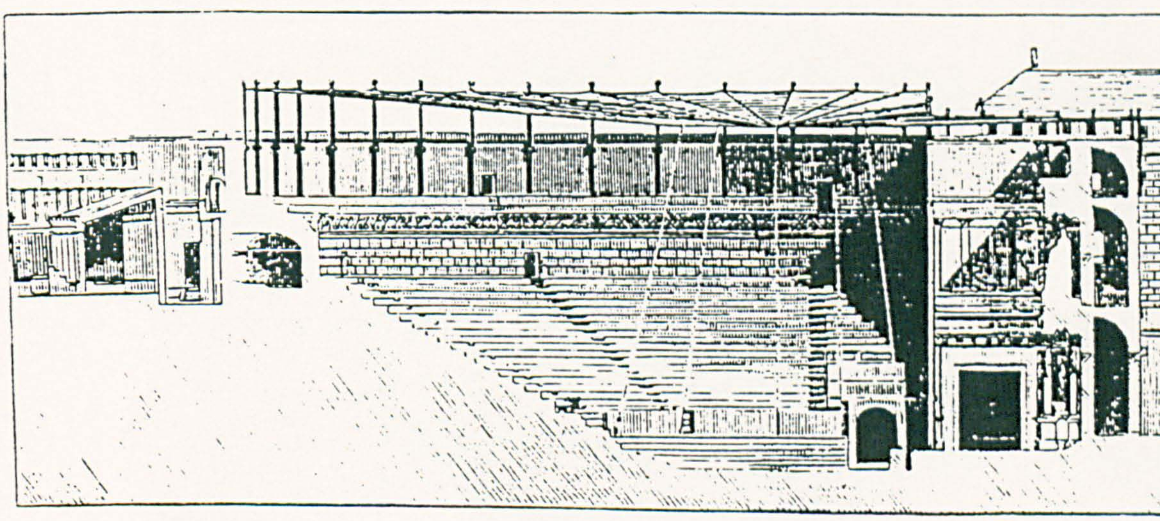


Fig. 1.15. Velarium, covering a Roman theatre to shelter the seats from sun and rain (1st c A.D.).

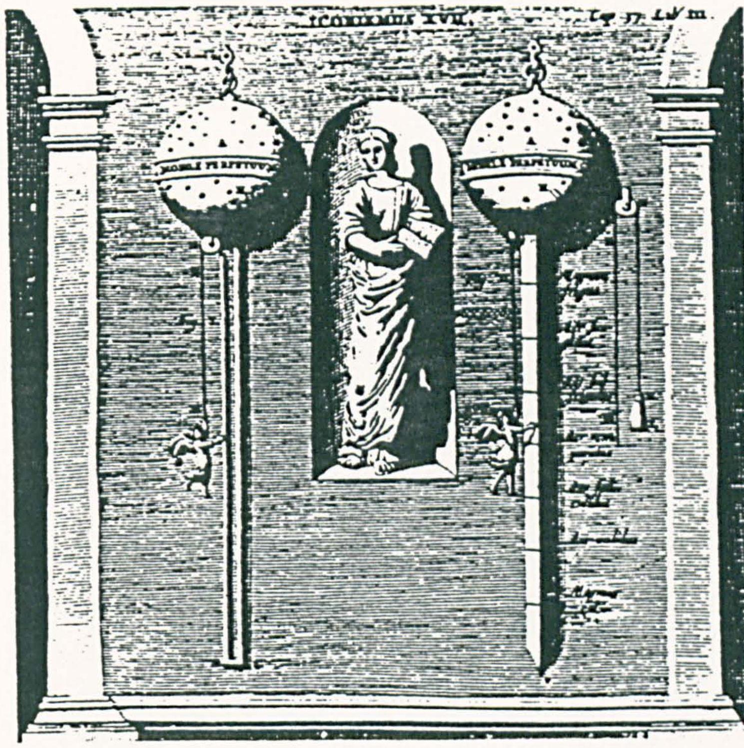


Fig. 2.1. Otto von Guericke's thermometer (1672). Almost twenty feet high, it was mounted on the north side of a building in Magdeburg. The angel, rising and falling, indicated the temperature on a scale which ranged from *magnum calor* to *magnum frigus*

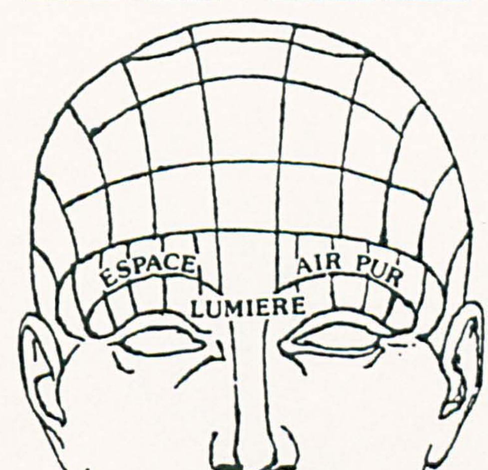


Fig. 2.2. Jean Baptiste Andre Godin. The embodiment of natural elements in physiognomy; diagram of the head showing the relationship of light, pure air and space.

Fig. 2.3. Pieter de Hoogh, The Card Players, showing the interior of a 17th c. Dutch house with daylighting controlled by window fittings.

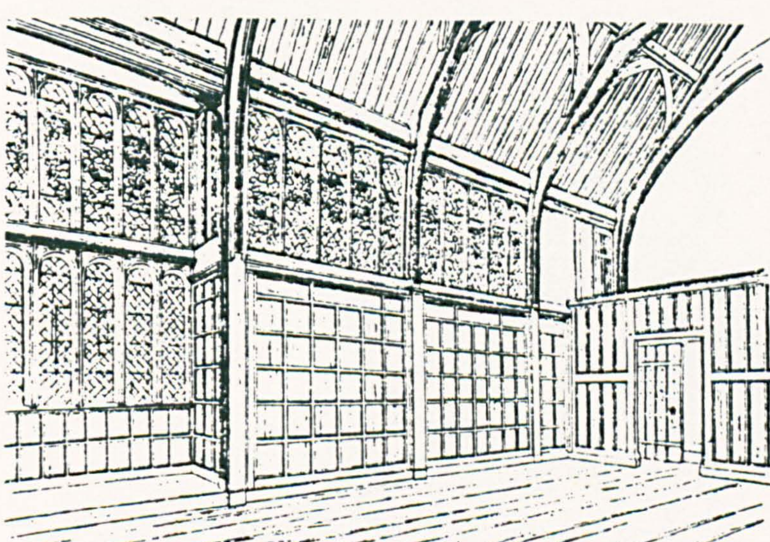


Fig. 2.4. Ockwells Manor, Bray, Berkshire (c 1465), interior of Hall in a half-timbered house.

Fig. 2.5. Robert Campin, The Annunciation (c 1425), detail. The window is typical of a wealthy house of the 15th century and shows two types of folding shutter and a fenestral. In houses with large windows with transomes it was usual for the shutters to seal off the lower lights leaving the upper ones open at a height where the light would be advantageous but the draught would be least inconvenient. The small amount of glazing is confined to the two lights above the transome.

Fig. 2.6. Hardwick Hall, Derbyshire (1590-1597) . . . with generous windows that brought rooms and galleries into visual partnership with the surrounding gardens and parkland.

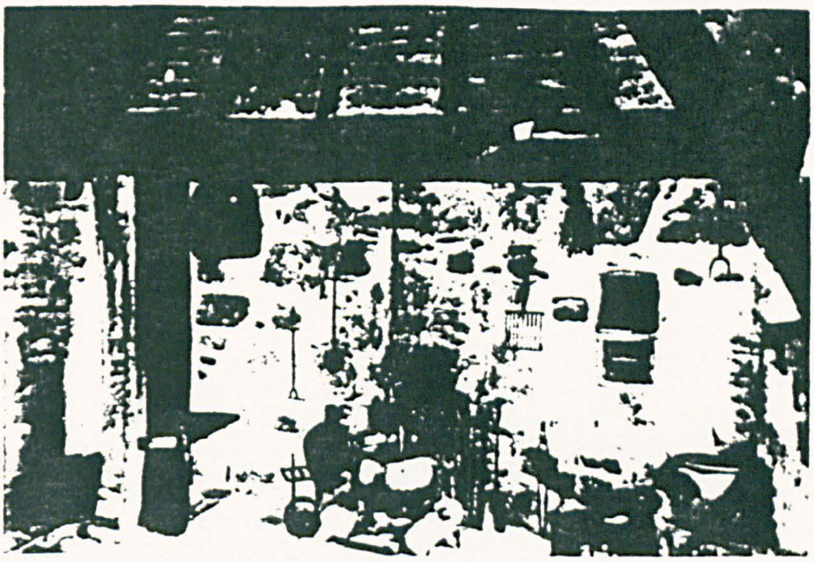


Fig. 2.7. Traditional inglenooks; the smoke bay in a cruck-built house, Stangend, Danby, 1704, reconstruction at the Ryedale Folk Museum, Hutton le Hole, Yorkshire. The witch post on the left is typical of this region as are the small built-in cupboards at the back of the fire to the right. Inglenook in a traditional English farmhouse, showing a bench within the sheltering chimney breast, benches on either side, and a draft-proofing curtain on the left.

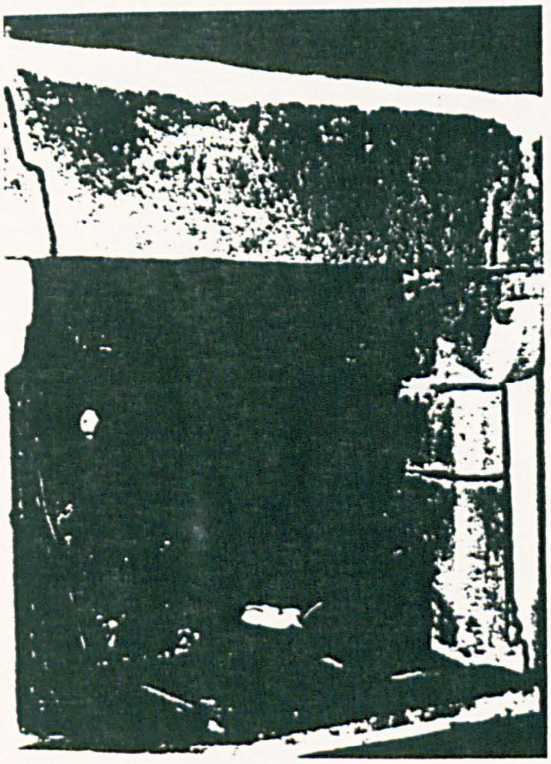


Fig. 2.8. Fireplace with smoke hood, enclosing fireplace activities, Don Farm, St. John, Jersey, dated 1673, re-erected at the Jersey Museum. The smoke hood of wattle and daub was inevitably translated into stone and is found as far north as Yorkshire and Scotland as well as in France.

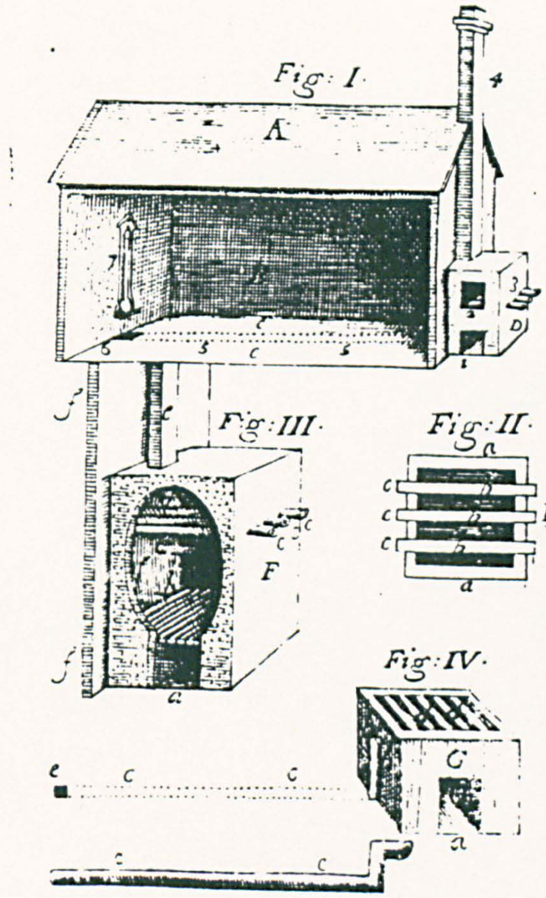


Fig. 2.9. John Evelyn, early furnace heating system for a hothouse (c 1650). The fire is located outside the building it serves. The combustion chamber is raised above the ash pit and induction air chamber by means of a grating. An ingenious arrangement of combustion air supply and fresh air inlet insures positive ventilation and air circulation within the hothouse. The combustion air runs through a pipe which is located under the floor. As air is drawn into the fire, fresh air must enter the room through tubes which pass through the combustion chamber, thereby warming the air. A thermometer is located on the far wall to assist the operator in maintaining constant temperature.

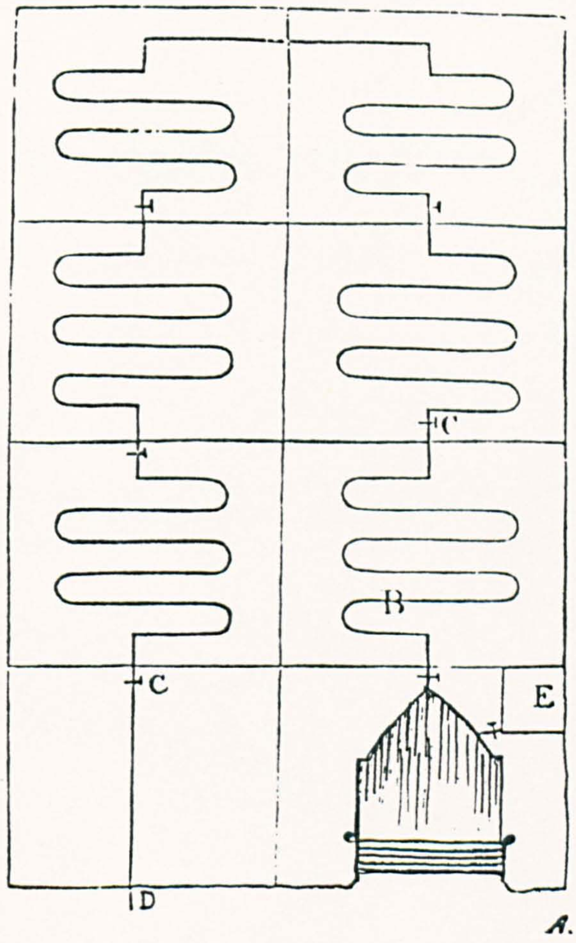


Fig. 3.1. Schematic drawing of one of the earliest steam heating systems (c 1730). The steam is not re-circulated, but passes through to the outside of the building (D). Water in the boiler must be replenished from reservoir (E)

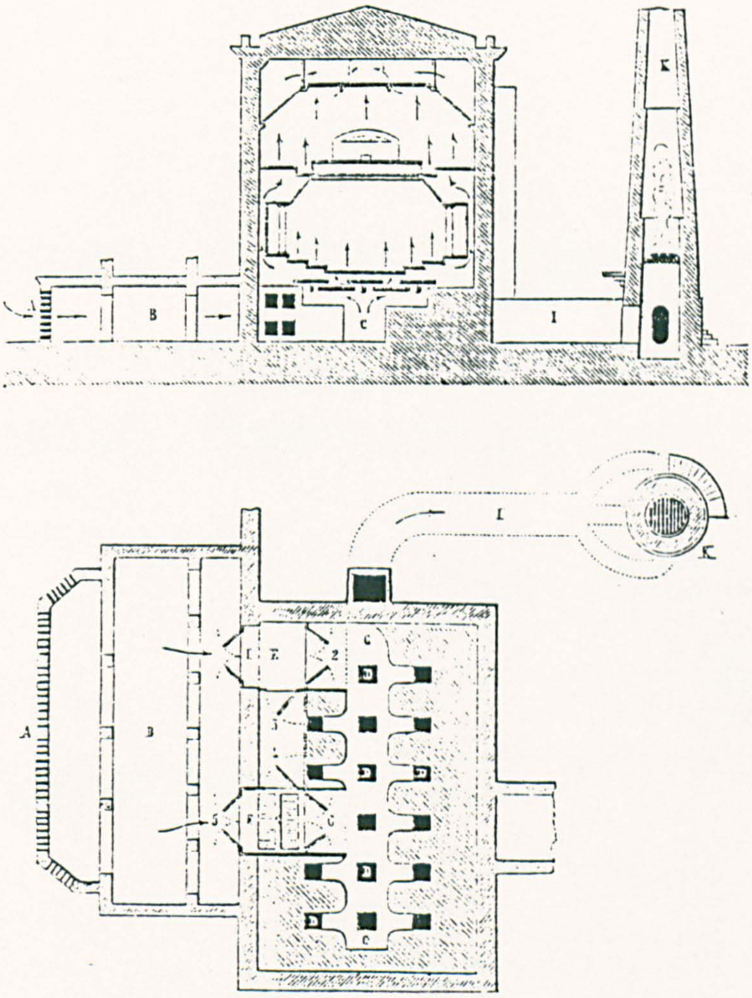


Fig. 3.2. House of Commons, London (1840-1865), section and plan showing the thermo-draught ventilating system designed by David Boswell Reid. Fresh air passed a cotton wool screen and then through a bag of ice hanging in duct area (B).

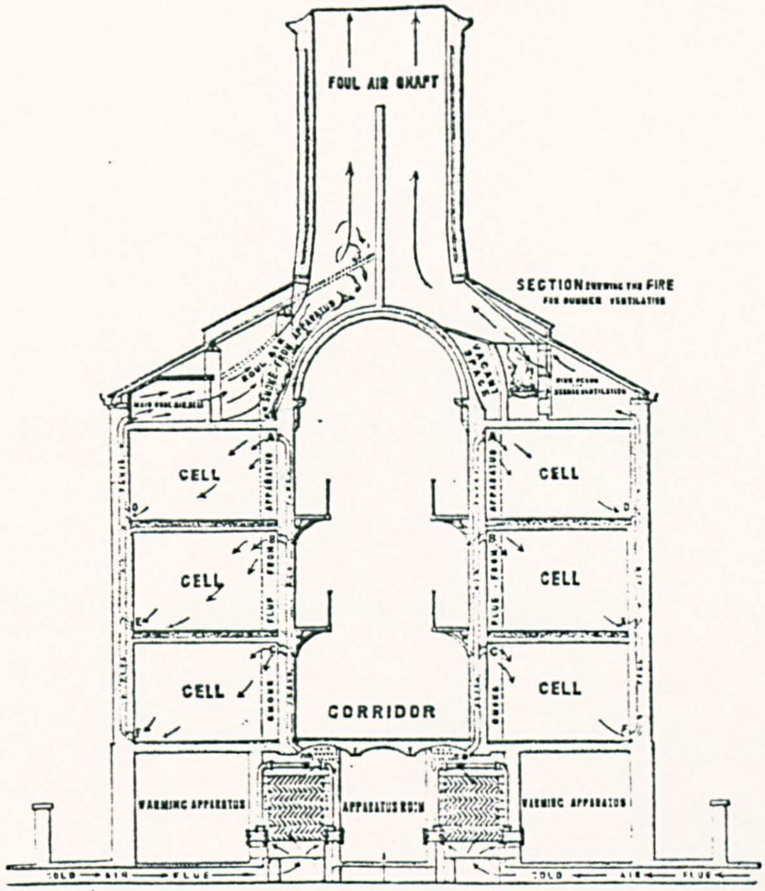


Fig. 3.3. Joshua Jebb, Pentonville Prison, London (1841-42), section showing structural and environmental systems.

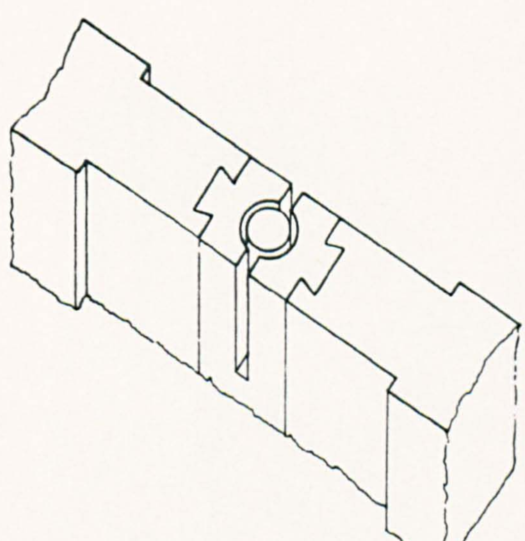


Fig. 3.4. George Dance the Younger, Southwark Compter (1785), ventilation slot; a construction detail developed for London prisons fitted into very small sites to prevent the surreptitious passing of messages and articles in and out through ordinary ventilation grilles.

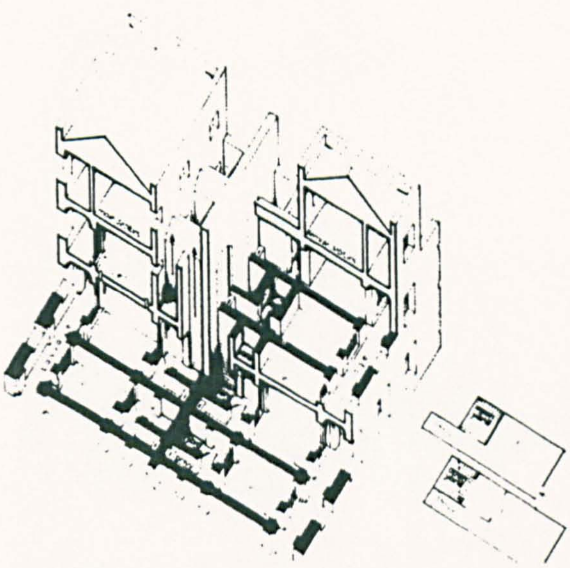


Fig. 3.5. Southwark Compter, Analytic drawing of Dance's design, showing ventilation routes.

Fig. 3.6. Windmill ventilator designed by the Rev. Stephen Hales, erected in 1752 by order of the Aldermen of the City of London on the roof of Dick Whittington's Gate at Newgate Prison.

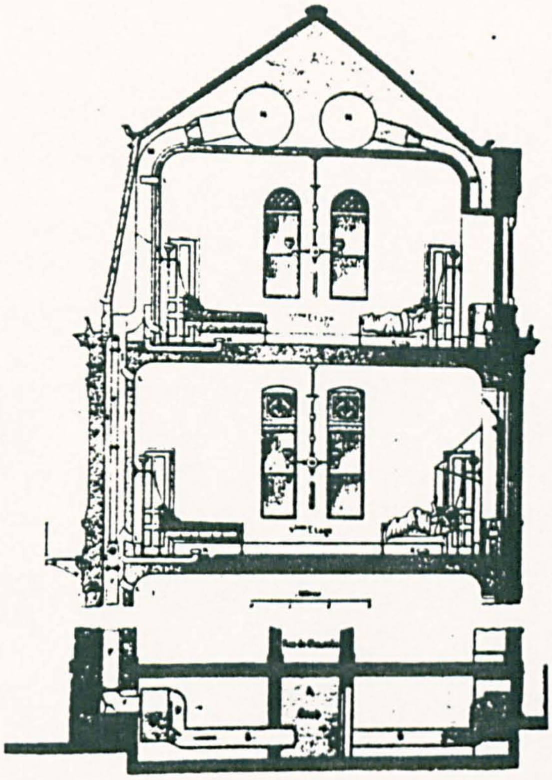


Fig. 3.7. New York Hospital, 1875-77. Section through patient wing showing arrangement of lighting and ventilation.

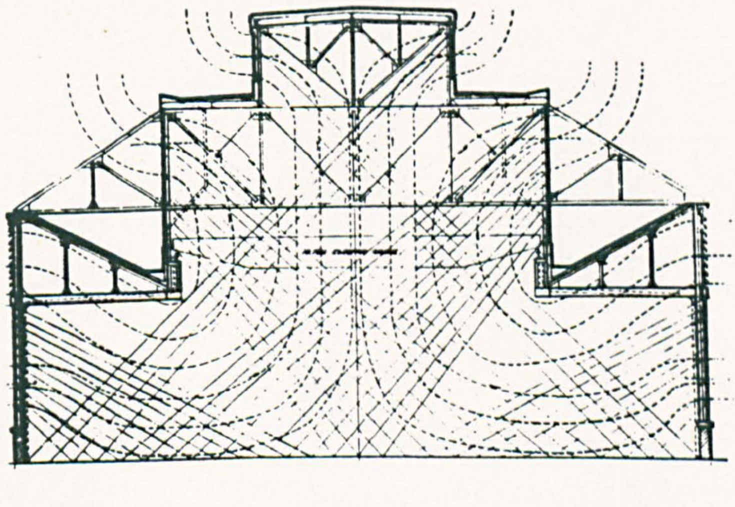


Fig. 3.8. Albert Kahn, Packard Motor Car Company forge shop, Detroit (1911). Section showing structure with paths of light and air circulation indicated.

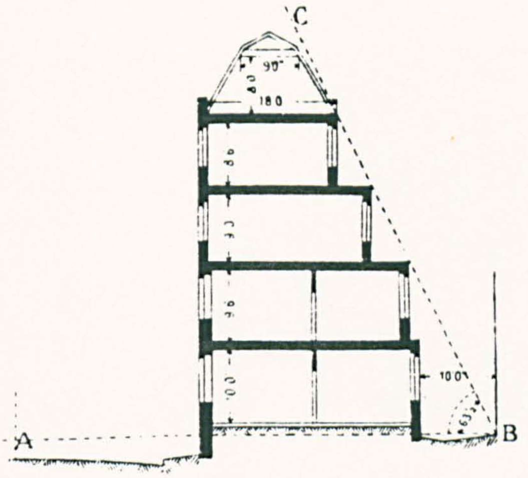


Fig. 3.9. Open space at the back of the house as required by the London Building Act of 1894.

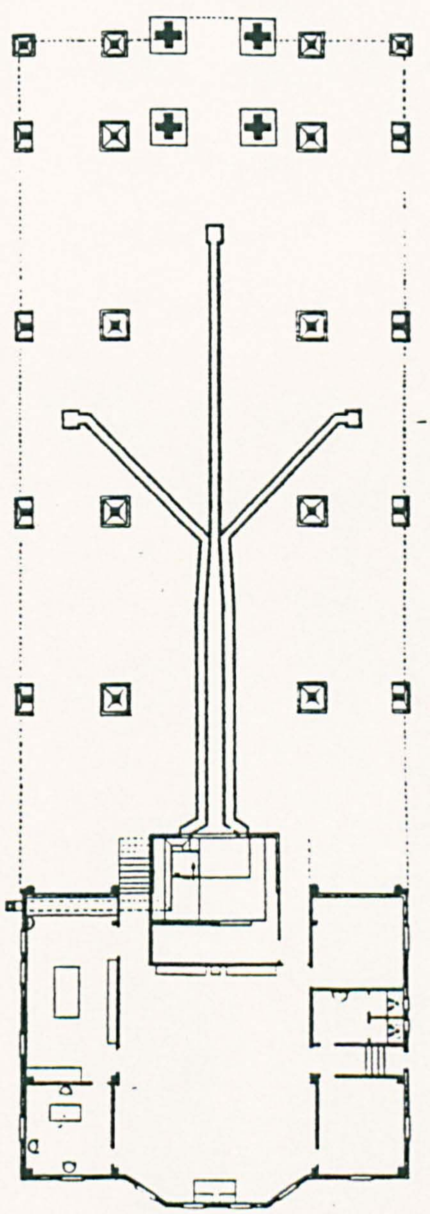


Fig. 5.1. Auguste Perret, Church of Notre Dame du Raincy (1923)Plan of the basement with heating ducts and the boiler placed in the position of the Crypt of the Martyrs.

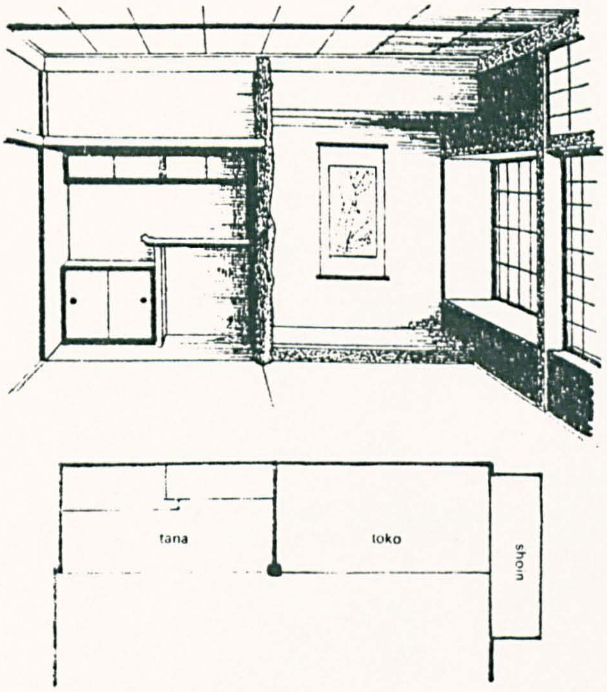


Fig. 5.2. The location and partitioning of the toko and the tana in the traditional Japanese home.

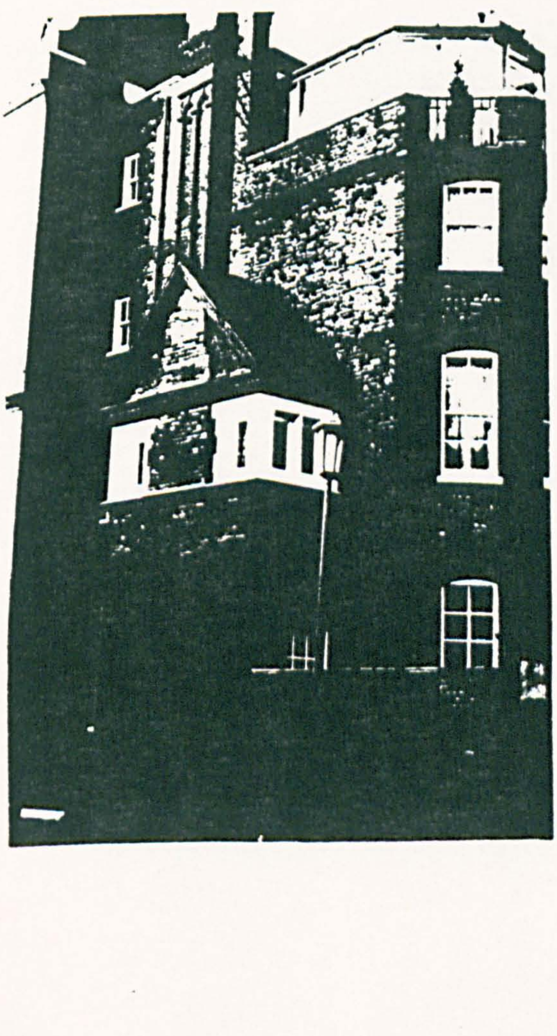


Fig. 5.3. Inglenook, Chelsea, London, exterior showing windows.

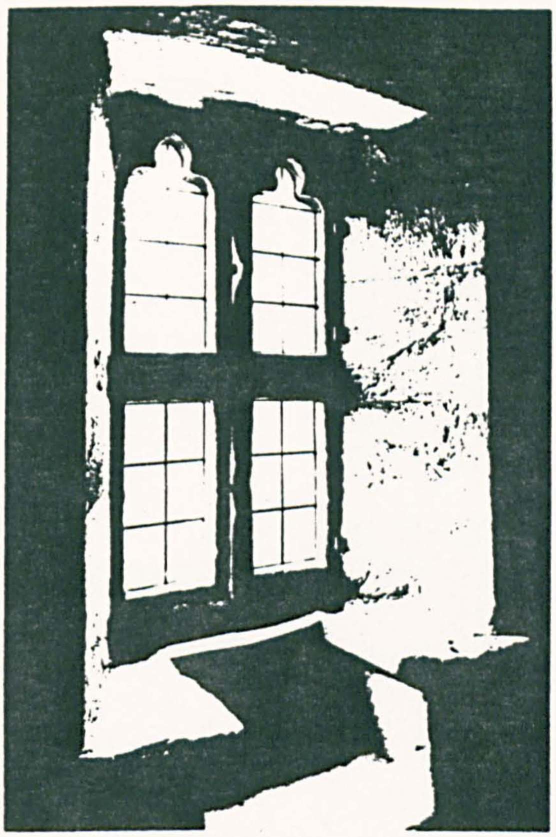


Fig. 5.4. Preston Patrick Hall, Westmorland (14th c), oriel with window seat. The seat would have had cushions in the Middle Ages. The window might not have been glazed originally. It had double shutters for upper and lower half whose hinges can still be seen. Upper would be opened to admit light, lower closed to exclude draughts.

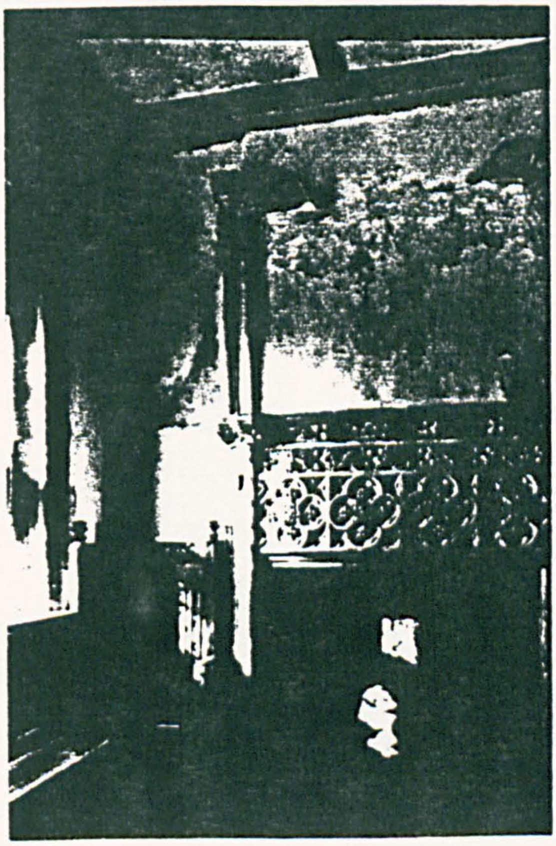


Fig. 5.5. Wall fireplace with window seat, late 15th or early 16th c. an elaborate and finely carved example of its period . . .the fitted seating is characteristically early Tudor.

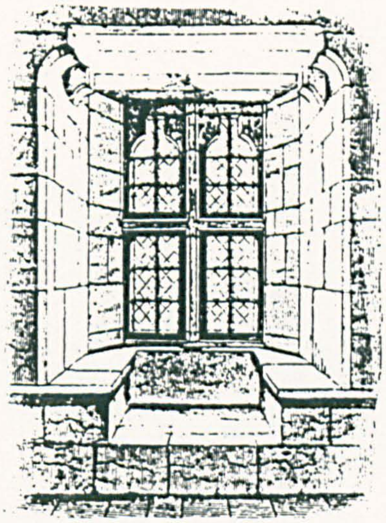


Fig. 5.6. Window seat at Alnwick Castle, Northumberlandshire (c 1310).

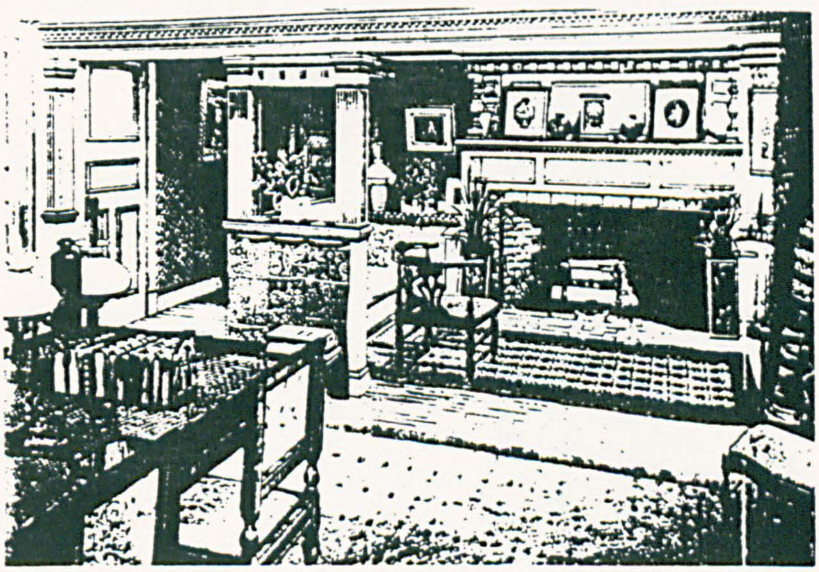


Fig. 5.7. One of the many inglenooks contemporary with Wright's design: Arthur Little, "Shingleside," Swampscott, MA, 1881, interior view of inglenook at one end of the Hall.

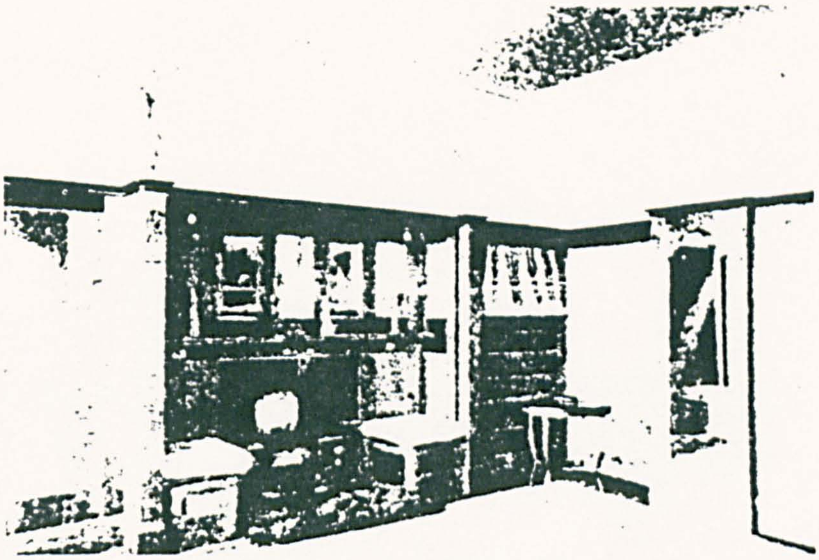


Fig. 5.8. H. E. Clifford, Stoneleigh, Kelvinside, Glasgow, showing a bedroom with inglenook.

Fig. 5.9. Parker and Unwin, A Living Room from, The Art of Building a Home, 1901.

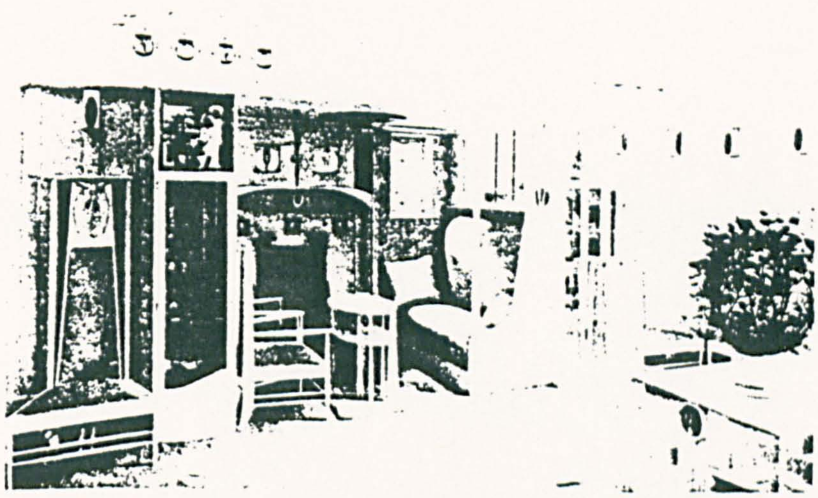


Fig. 5.10. Charles Rennie Mackintosh, Inglenook in the Waerndorfer Music Salon, Vienna (c 1902).

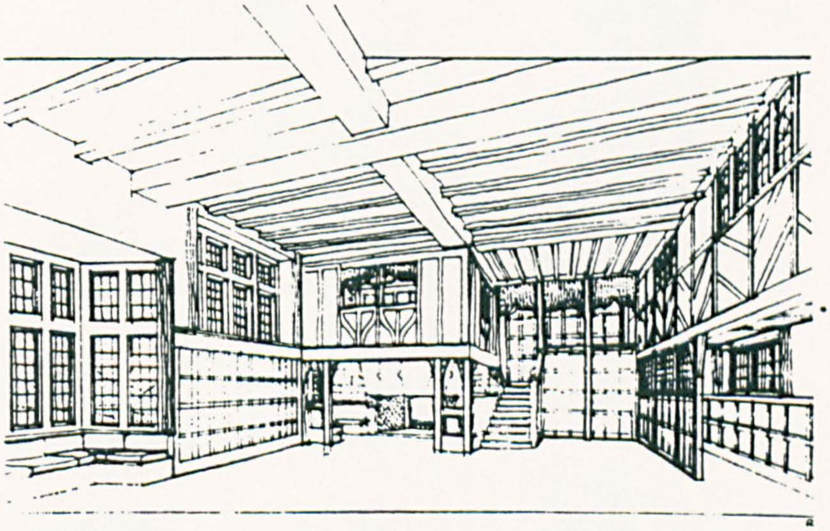
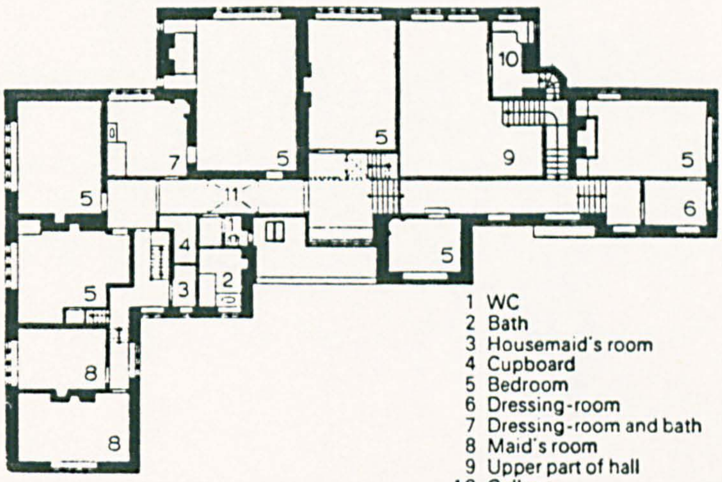
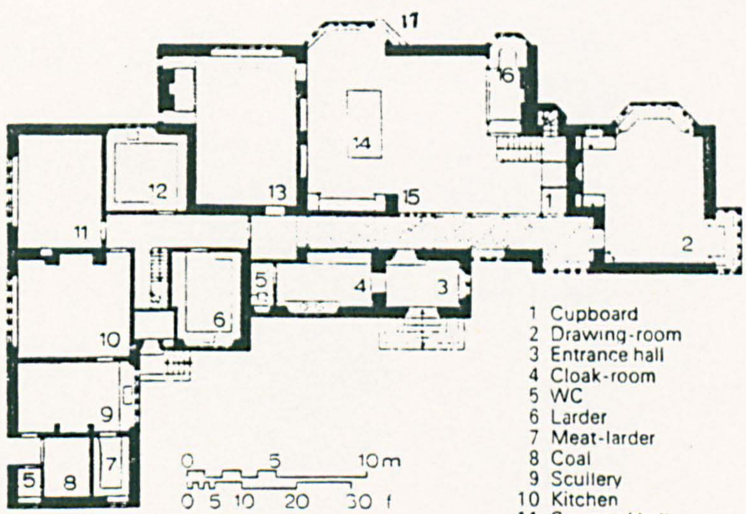


Fig. 5.11. M.H. Baillie-Scott, Blackwell on Lake Windermere, Westmoreland (1898), perspective of hall showing fireplace and inglenook.



1 WC
2 Bath
3 Housemaid's room
4 Cupboard
5 Bedroom
6 Dressing-room
7 Dressing-room and bath
8 Maid's room
9 Upper part of hall
10 Gallery
11 Skylight
12 Seat

Blackwell: Plan of first floor



Blackwell. Plan of ground floor

1 Cupboard
2 Drawing-room
3 Entrance hall
4 Cloak-room
5 WC
6 Larder
7 Meat-larder
8 Coal
9 Scullery
10 Kitchen
11 Servants' hall
12 Pantry
13 Dining-room
14 Billiard-table
15 Hall
16 Fire-place
17 Door to garden

Fig. 5.12. M.H. Baillie-Scott, Blackwell, 1898, plan of 1st floor and ground floor, showing location of inglenooks at perimeter of the house.

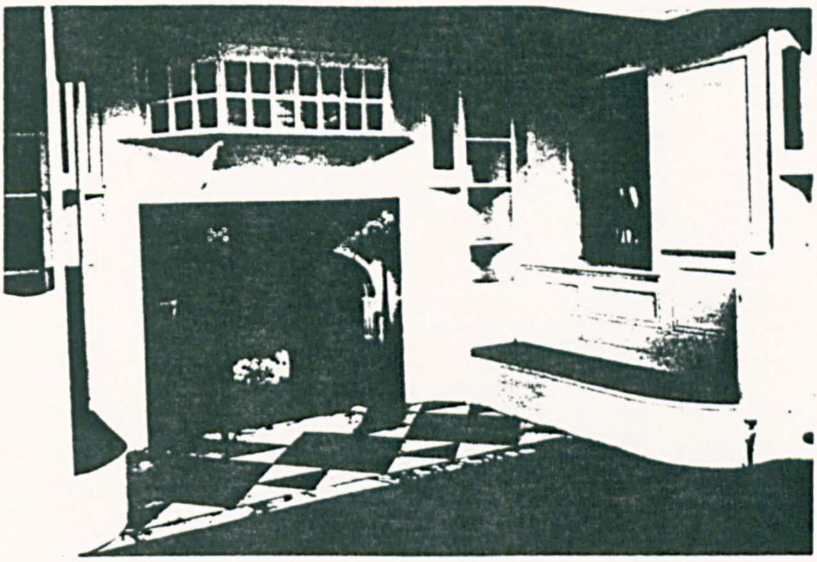


Fig. 5.13. Baillie-Scott, Blackwell, drawing room inglenook after restoration.

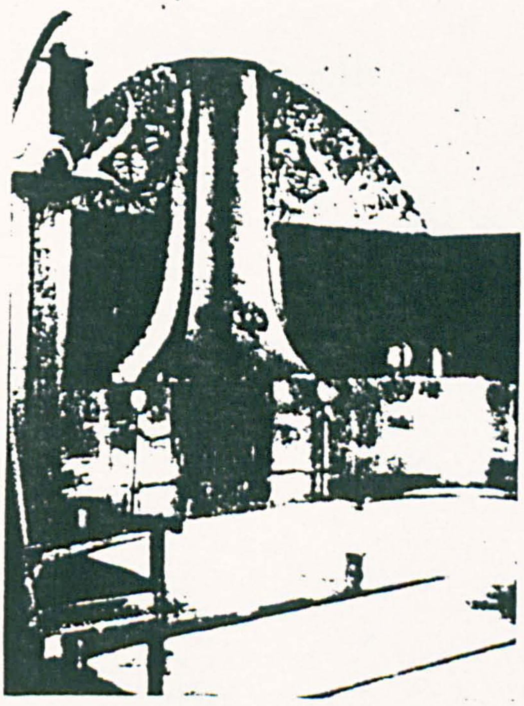


Fig. 5.14. George Walton, House at Weybridge, Surrey, fireplace / inglenook.

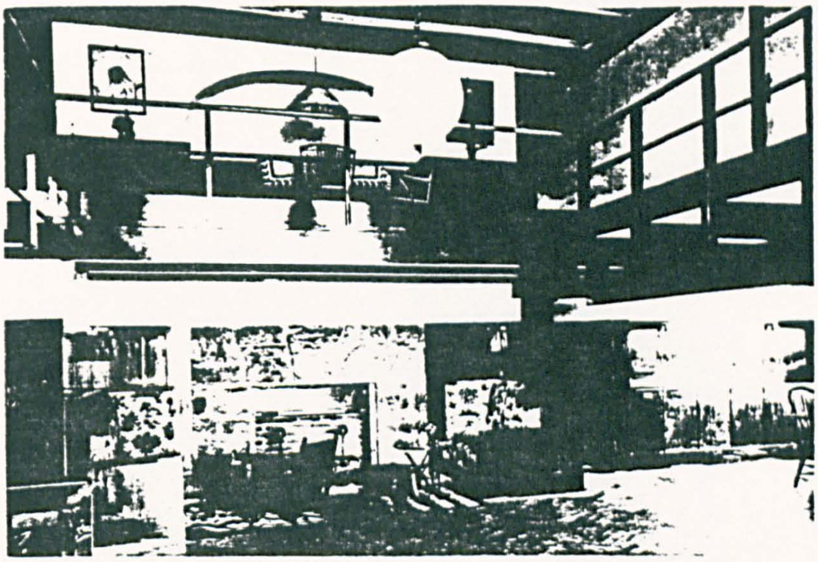


Fig. 5.15. Adolf Loos, Khuner Country House, Kreuzberg, Payerbach, Austria, view of gallery and sitting room; inglenook below and alcove above.

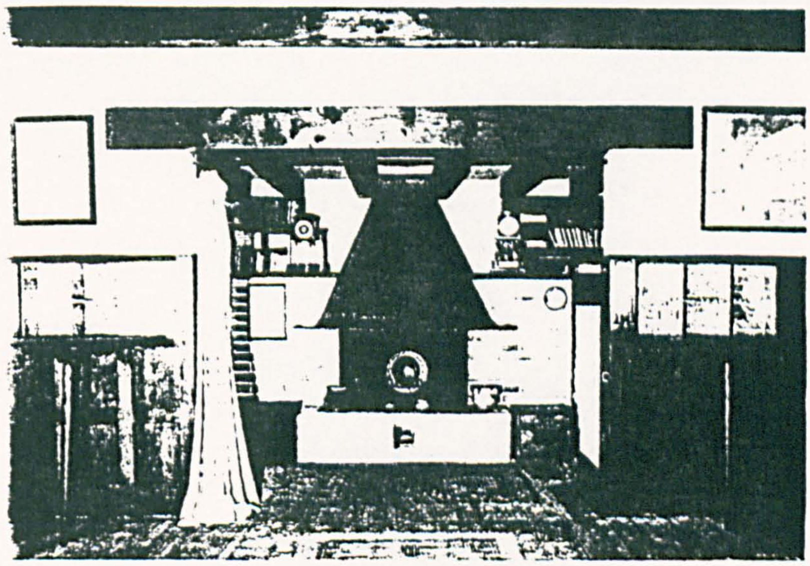


Fig. 5.16. Adolf Loos. Apartment for Adolf Loos (1903) showing inglenook. Here the materials have a semantic clarity -- the unplastered brick fireplace, the open beams on the ceiling, the wood panels that line the walls, the varying heights of the rooms. A wide opening places two rooms of different height and size in communication creating a semantic hierarchy. The drop in height creates the impression of the alcove being inside the living room.

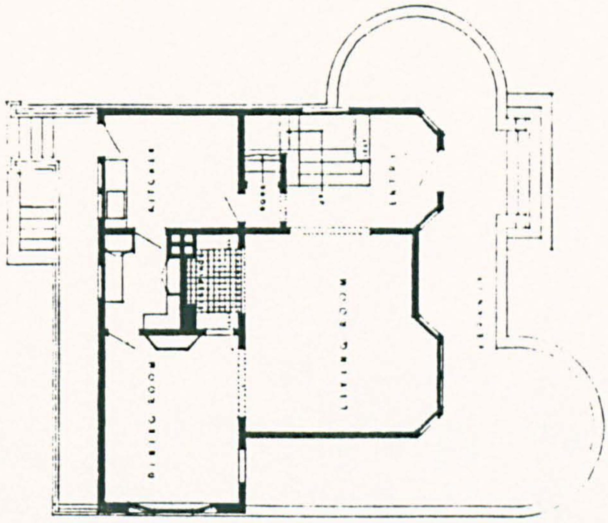


Fig. 5.17. F. L. Wright, architect's own home, Oak Park, IL. (1889), plan as it was originally built.

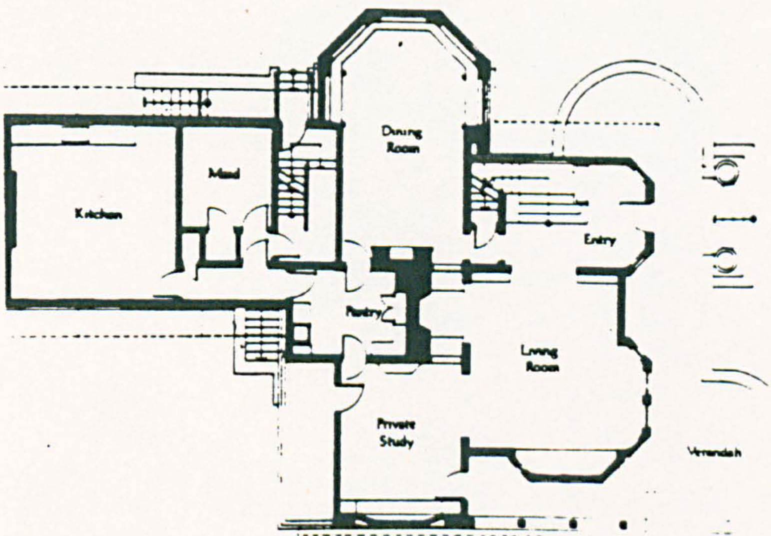


Fig. 5.18. F. L. Wright, home and studio, Oak Park, plan as it appeared around 1900. The Inglenook is in the 'centre of gravity' of the plan.

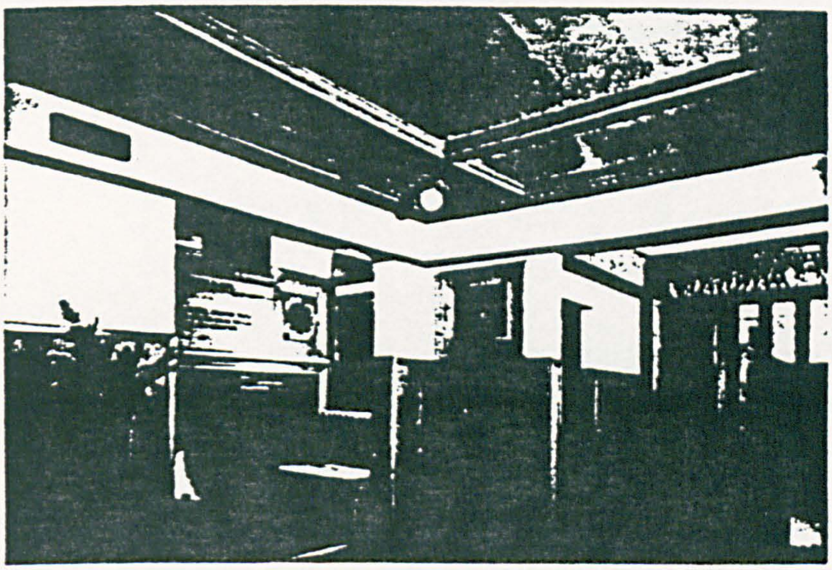
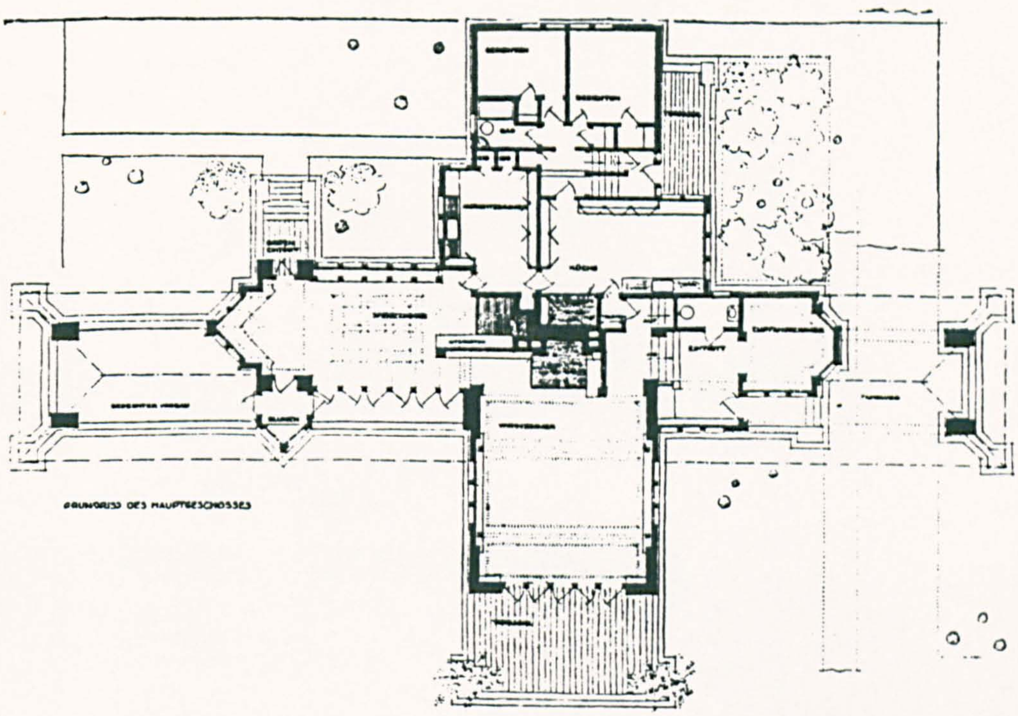


Fig. 5.19. F. L. Wright, home and studio, inglenook. It contains cushioned seats, a round-arched fireplace, a carved motto and a mirror above the mantle which gives the illusion of flowing space. The motto says:

Truth is Life.

Good friend around these
hearthstones speak no evil
word of any creature.



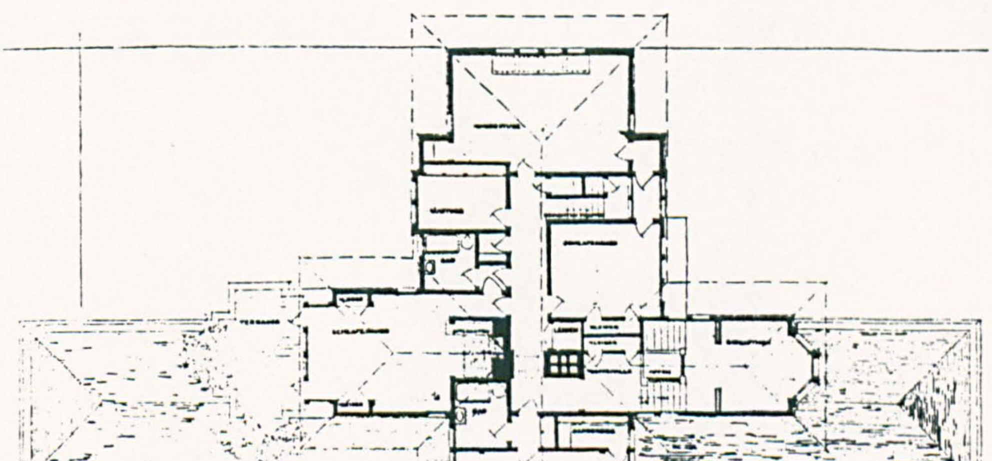


Fig. 5.20 F. L. Wright, Ward W. Willits House, Highland Park, IL. (1901) plans: (above) main floor and (below) upper floor.

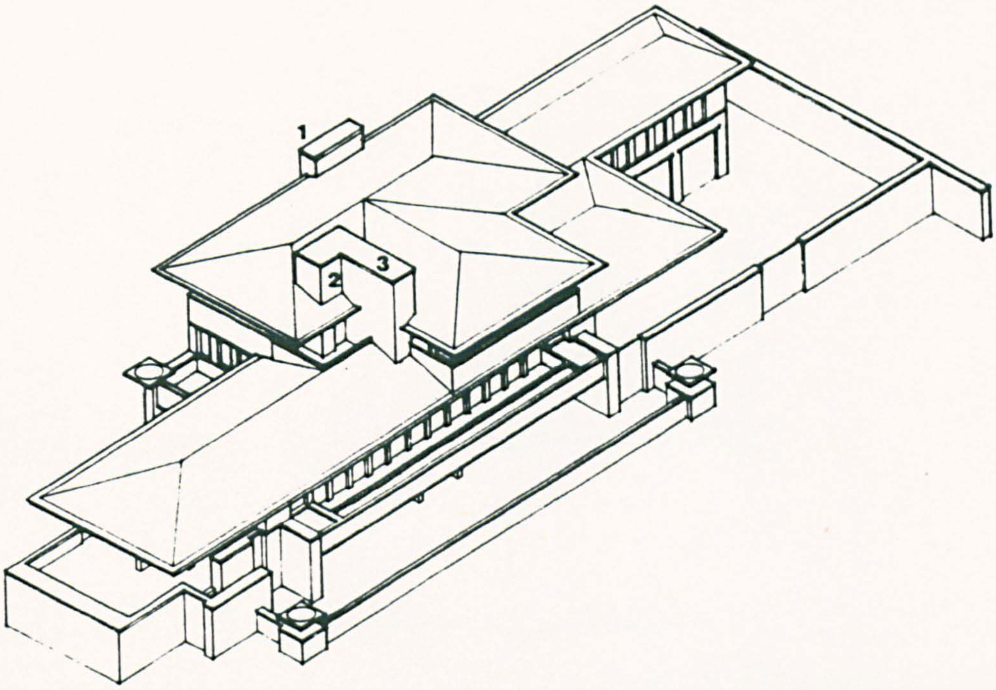


Fig. 5.21. F.L. Wright, Robie House, Oak Park, IL. (1908); massing of house with; 1. flue from boiler and vertical plumbing vents; 2. vent from living room; 3. main chimney.

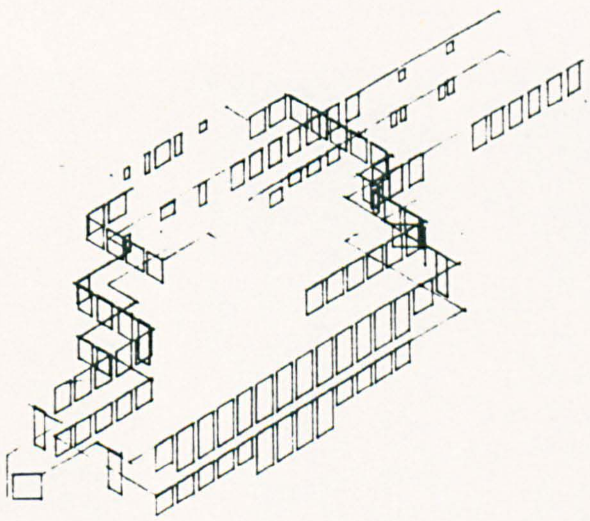


Fig. 5.22. Robie House, location of windows in relation to major forms shown above.

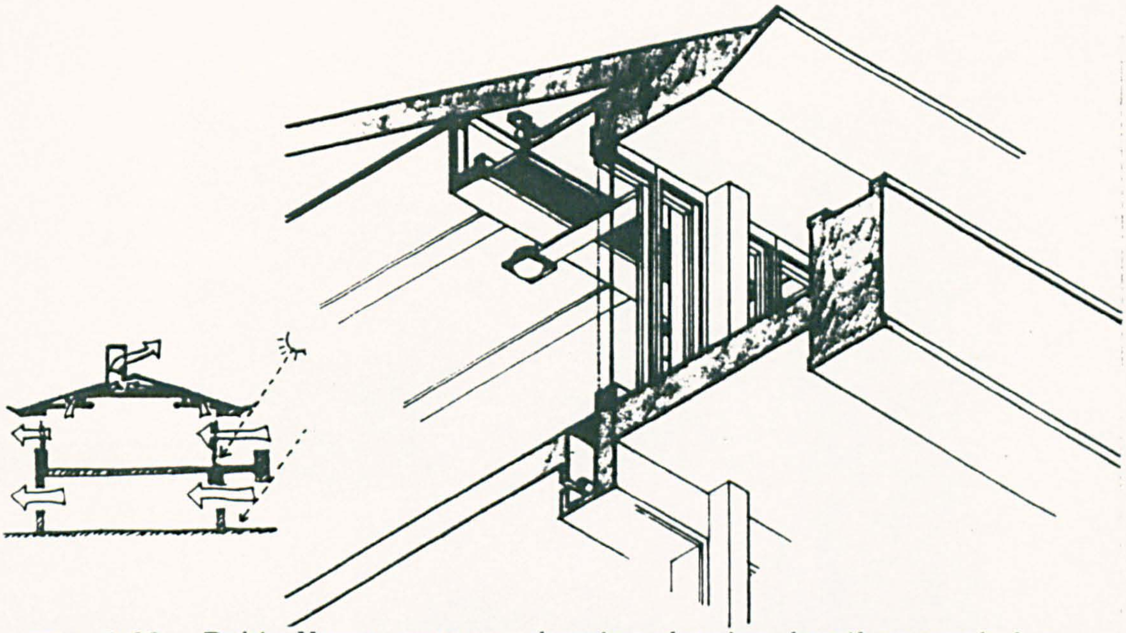


Fig. 5.23. Robie House, cutaway drawing showing detail at south face of living and dining rooms. Note deep shading provided by eaves, floor to ceiling glass doors, recessed perimeter finned-tube heating, 'sunlight' globes and 'moonlight' recessed incandescent bulbs. The pattern on each oaken grille is unique.

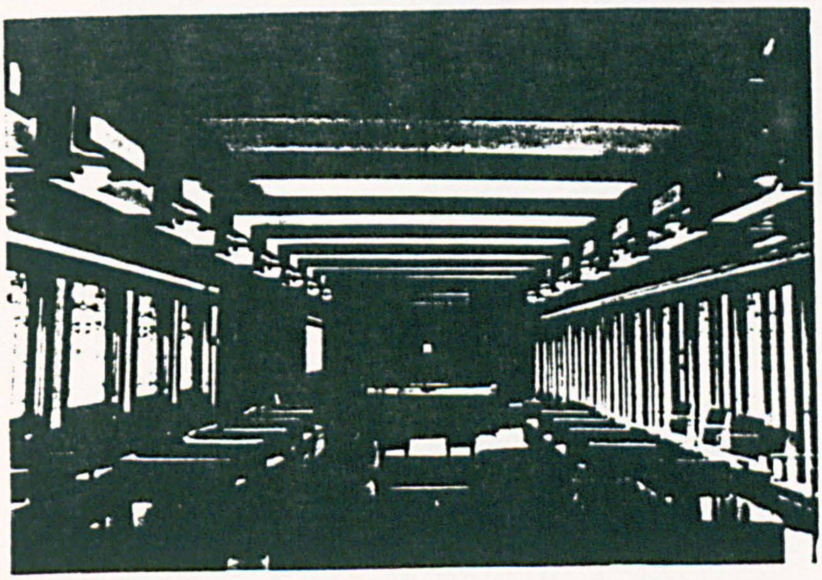


Fig. 5.24. Robie house, interior of living room which has been compared to a railway carriage in its proportions.

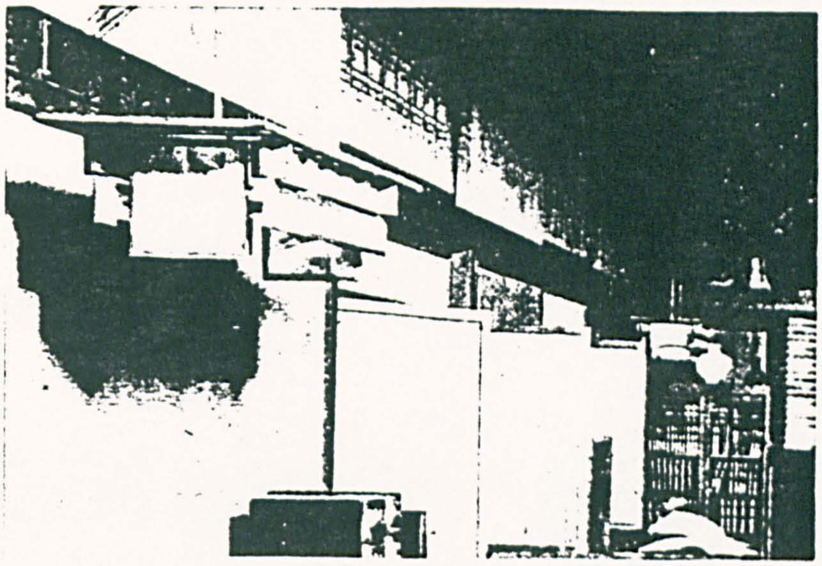


Fig. 5.25. F. L. Wright, Browne's bookstore, Chicago, IL, pendant light fixtures.

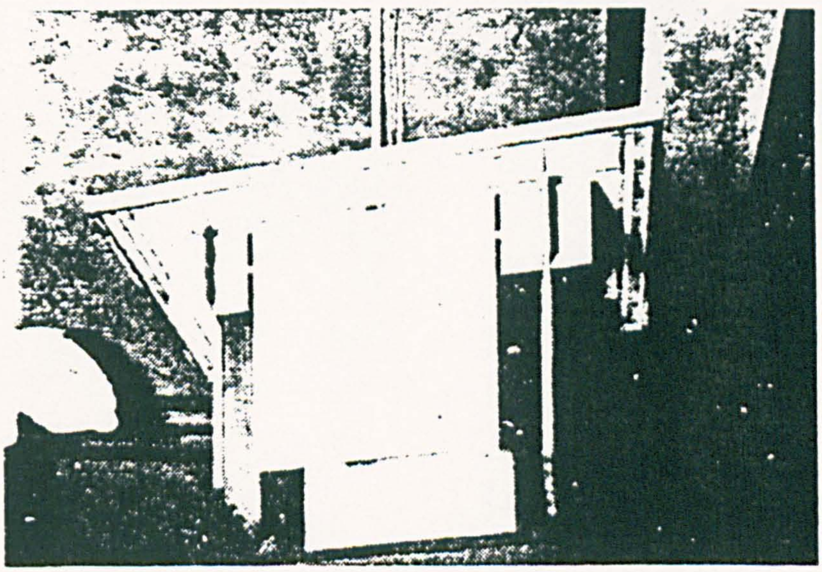


Fig. 5.26. Browne's bookstore, light fixture detail showing open-cornered construction.

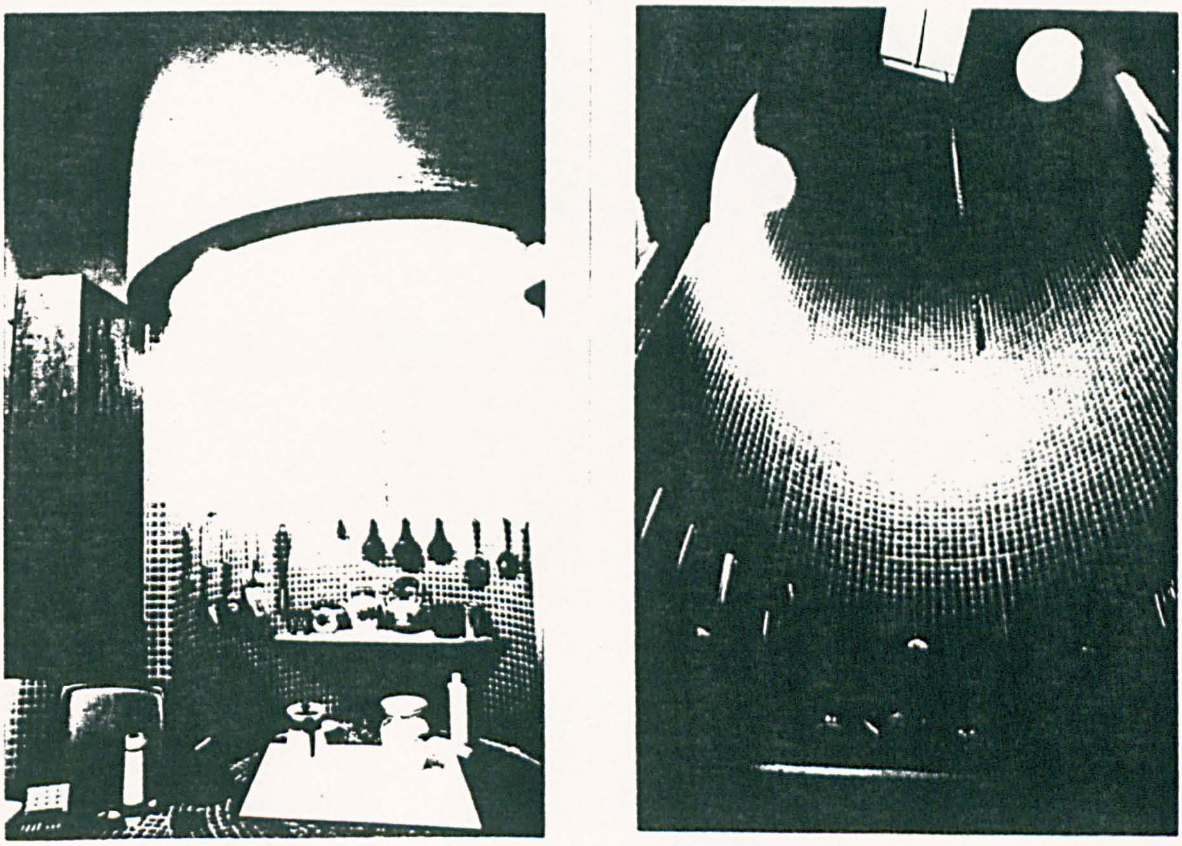
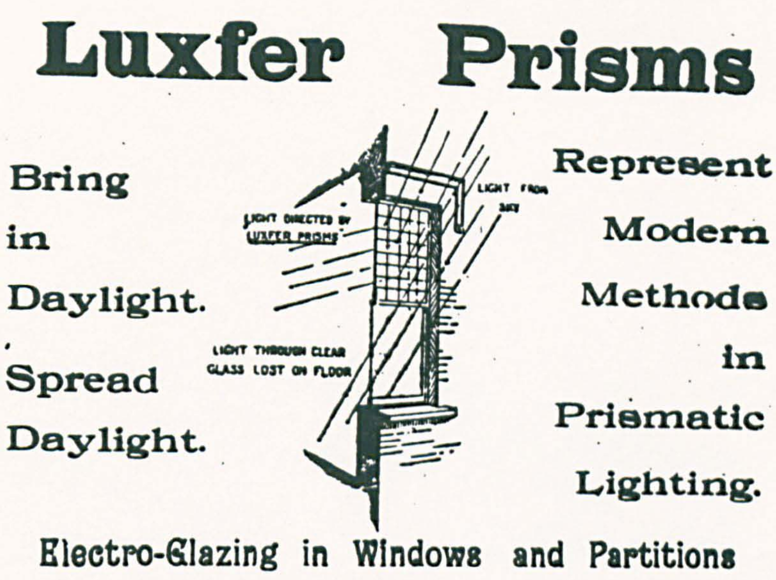


Fig. 5.27. F. L. Wright, Jester House, Taliesin West Compound, Scottsdale Arizona (c. 1980), Constructed 50 years after it was designed. View of kitchen venting area, typical of Wright's designs after 1920.



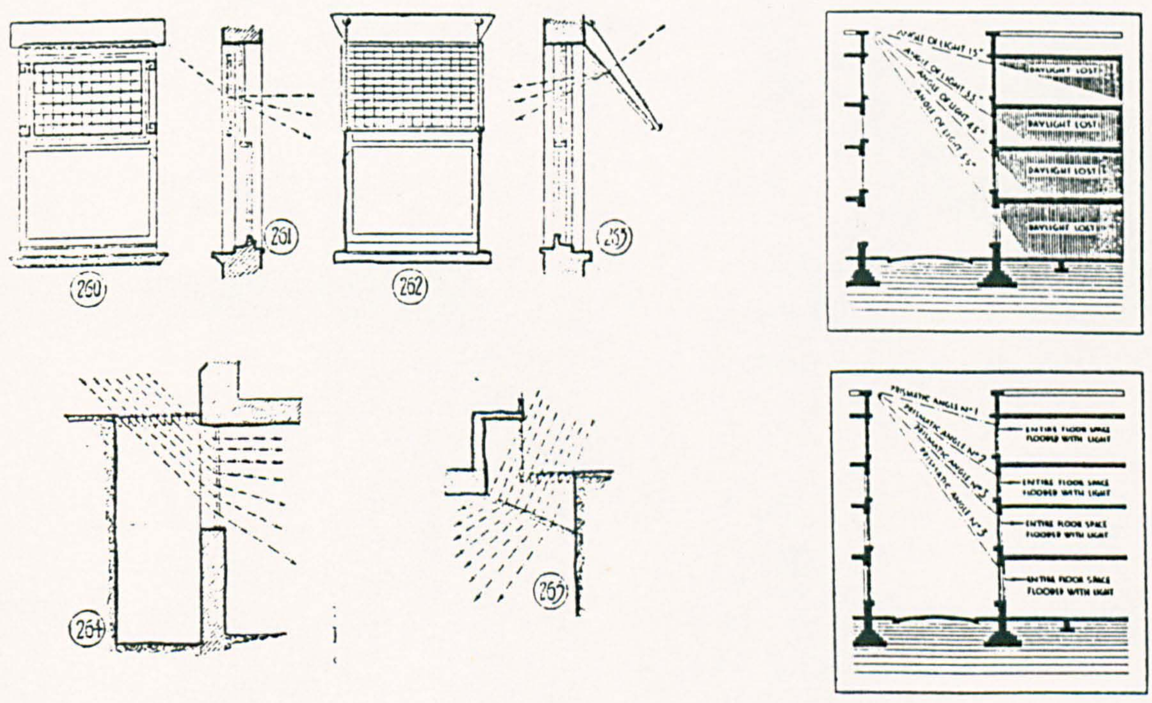


Fig. 5.28. Luxfer Light Prism Company, advertisement at turn of century and diagram, showing operation of prism. In the early 1900's Frank Lloyd Wright had a franchise for the exclusive use of this system in the Midwest U. S.

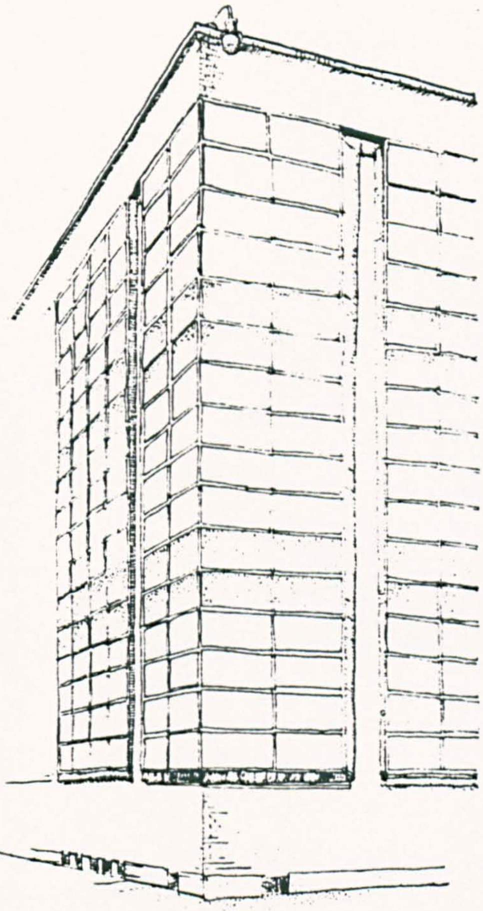


Fig. 5.29. Walter Gropius and Adolf Meyer, Fagus Factory, Alfeld an der Leine (1911). Dramatic spatial effects were achieved by the open corner, sheathed in glass.

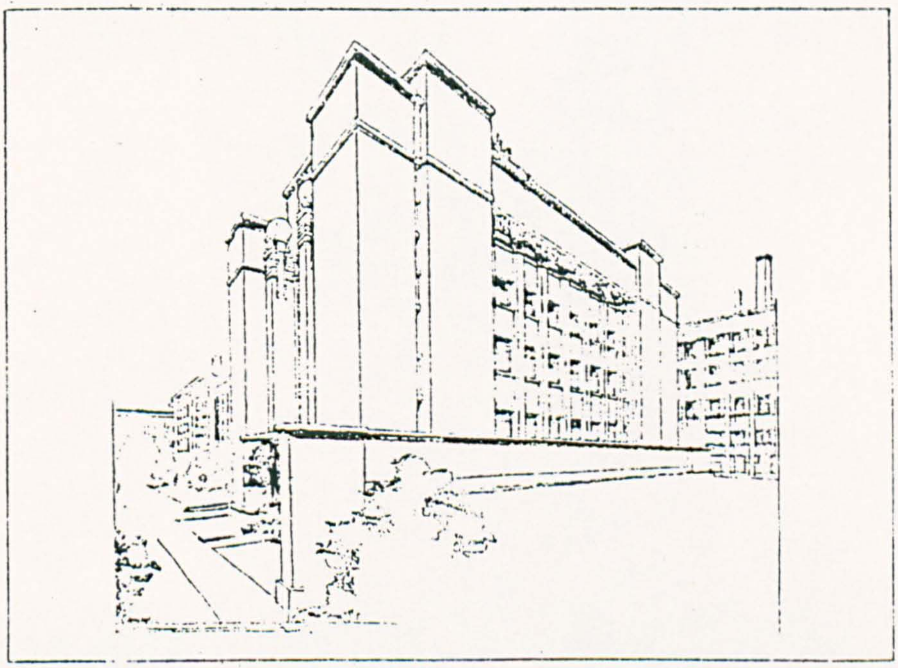


Fig. 5.30. F. L. Wright, Larkin Administration Building, Buffalo, NY (1906), called 'a cathedral of commerce' by contemporary publicists.

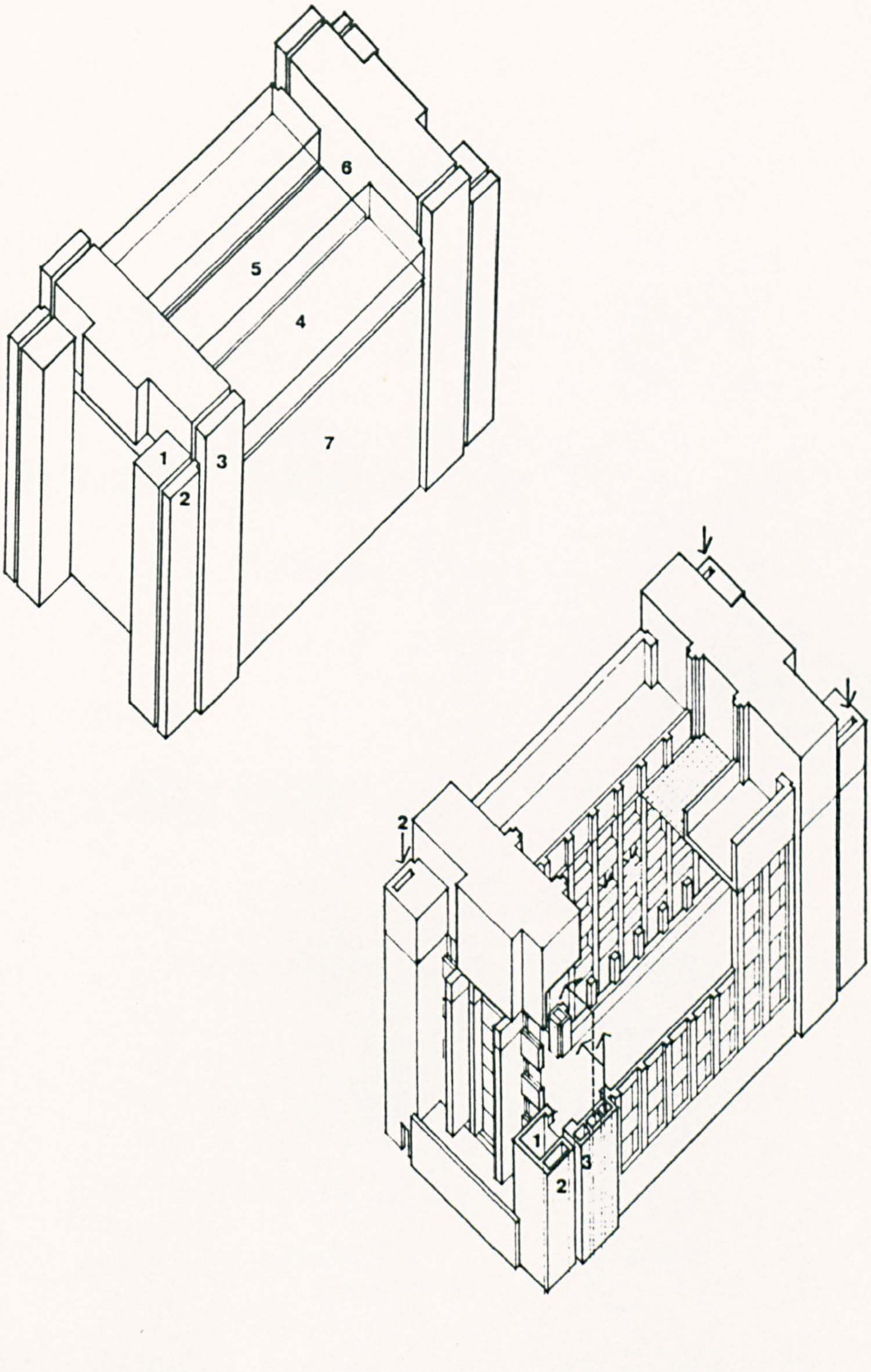


Fig. 5.31. Larkin Administration Building; Diagrammatic layout of major features: 1. stairtowers; 2. fresh air intake; 3. tempered air distribution, exhaust and utilities; 4. roof terraces; 5. skylight over courtyard; 6. conservatory / recreation area; 7. offices.

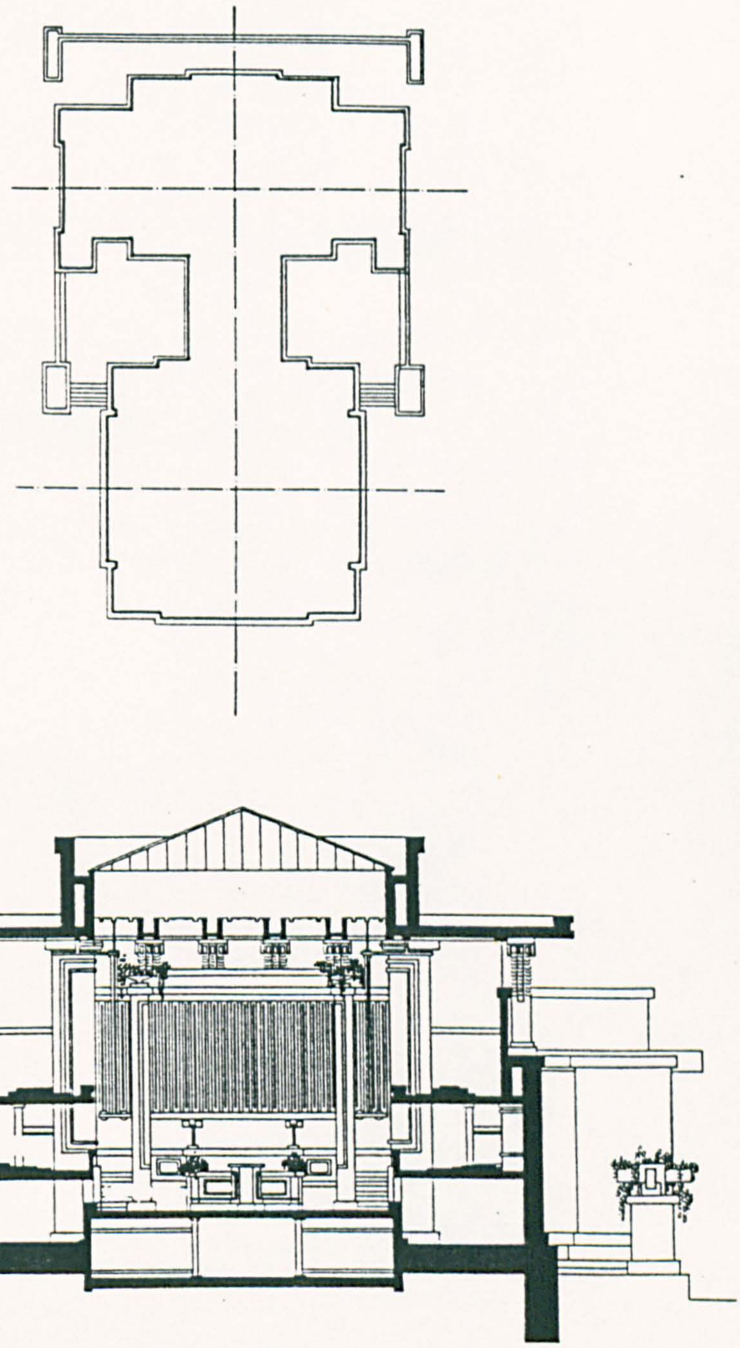


Fig. 5.32. F. L. Wright, Unity Church, Oak Park, IL.(1904-7) Plan and section.

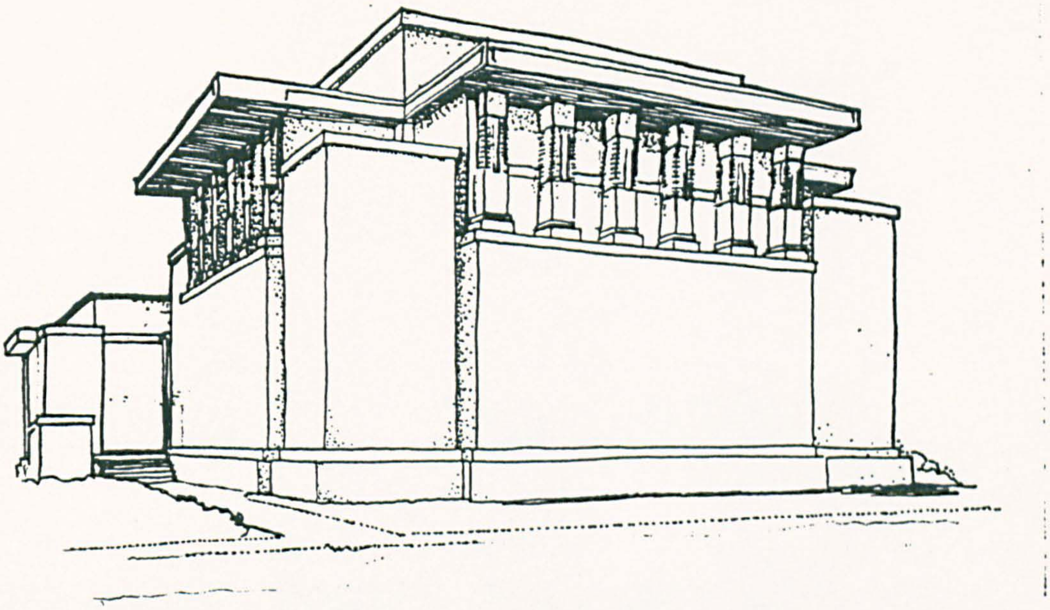


Fig. 5.33. Unity Church, perspective view showing eaves overhanging the banded windows and the sliced, detached corner stairtowers.

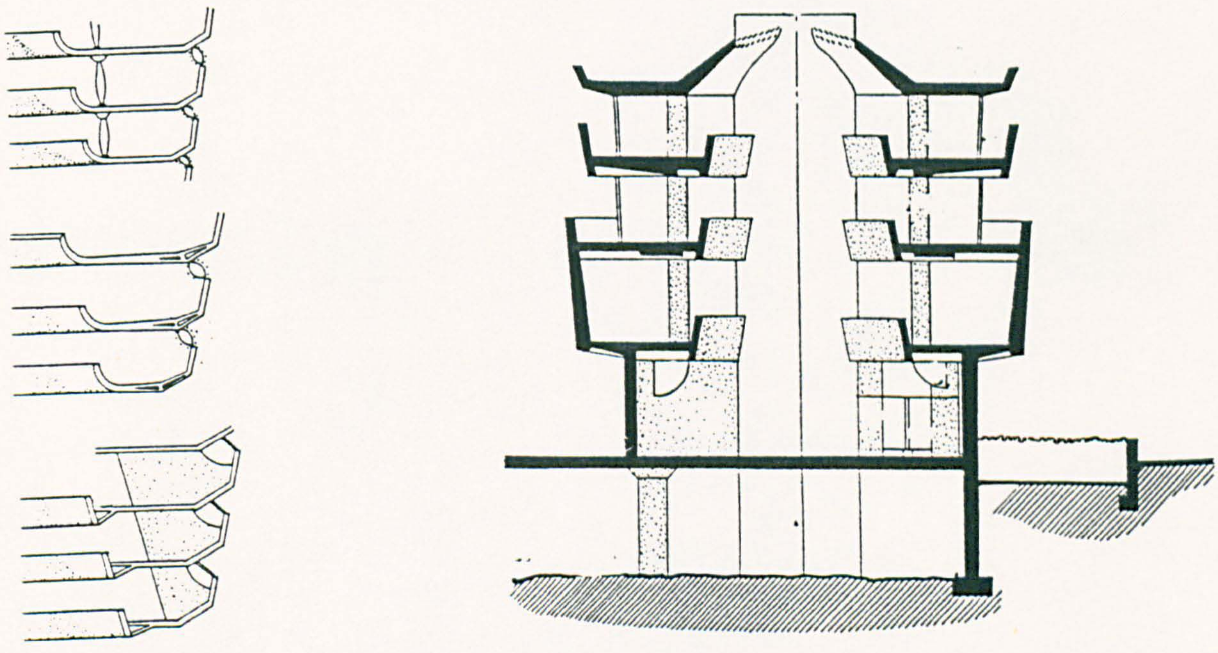


Fig. 5.34. F.L. Wright, Guggenheim Museum, New York (1956-59) Schematic cross section of (right) tower and monitor and, (left) ramp lighting as the concept developed from early stages with columns, top, to the use of 'webs' at bottom, with ductwork carried beneath the ramp, as it was finally built; Wright described 'the outer wall of the spiral, pierced by a continuous light trough cut into the side of the building like a screw thread. This is the source of both natural and artificial illumination.' However, The New York Fire Code prevented the use of glass tubing.

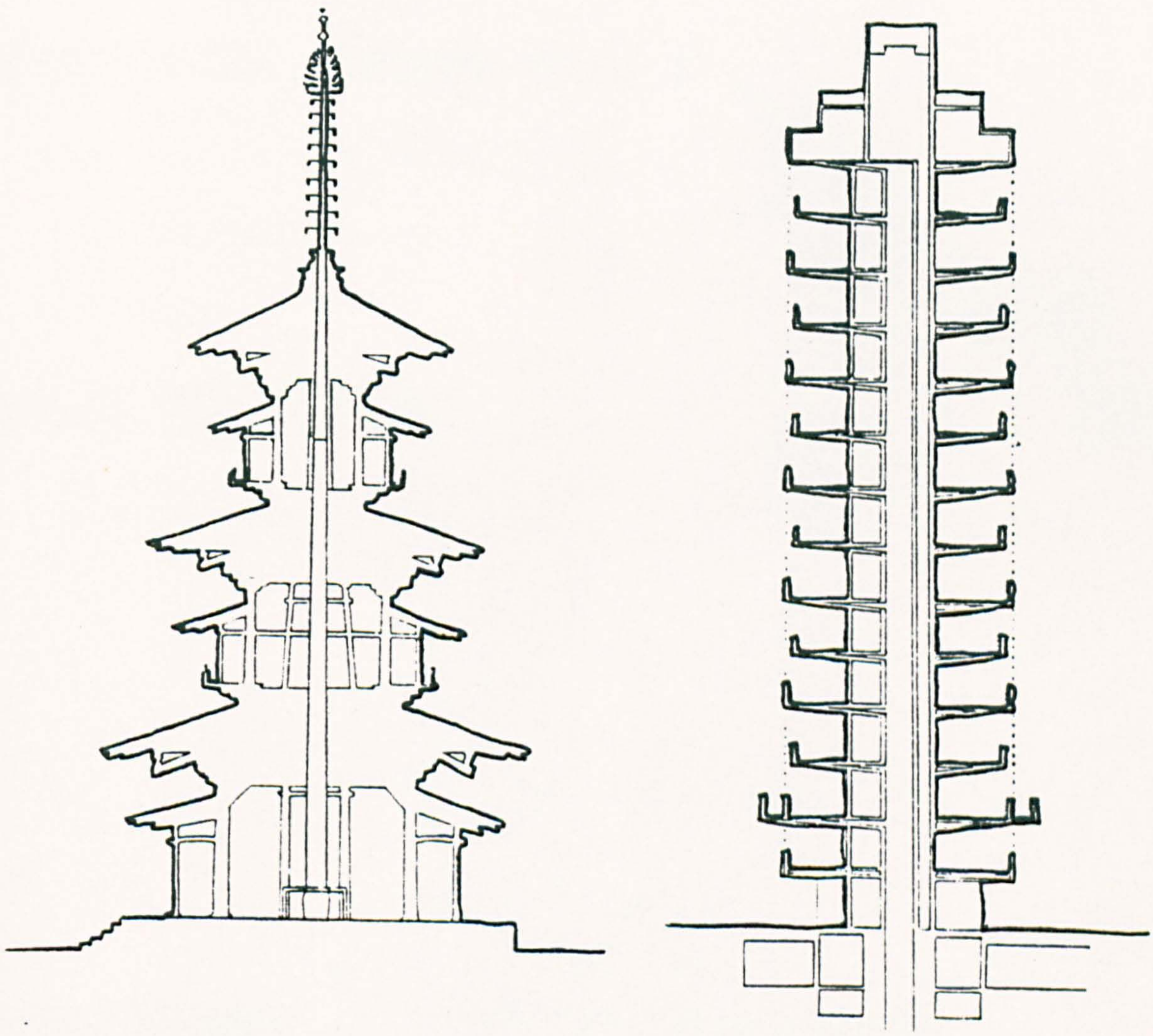


Fig. 5.35. (left) Johnson's Wax Administration Building Research Tower Addition, Racine, WI, (1947-50). (right) East Pagoda of the Yakushiji at Nara, Japan.

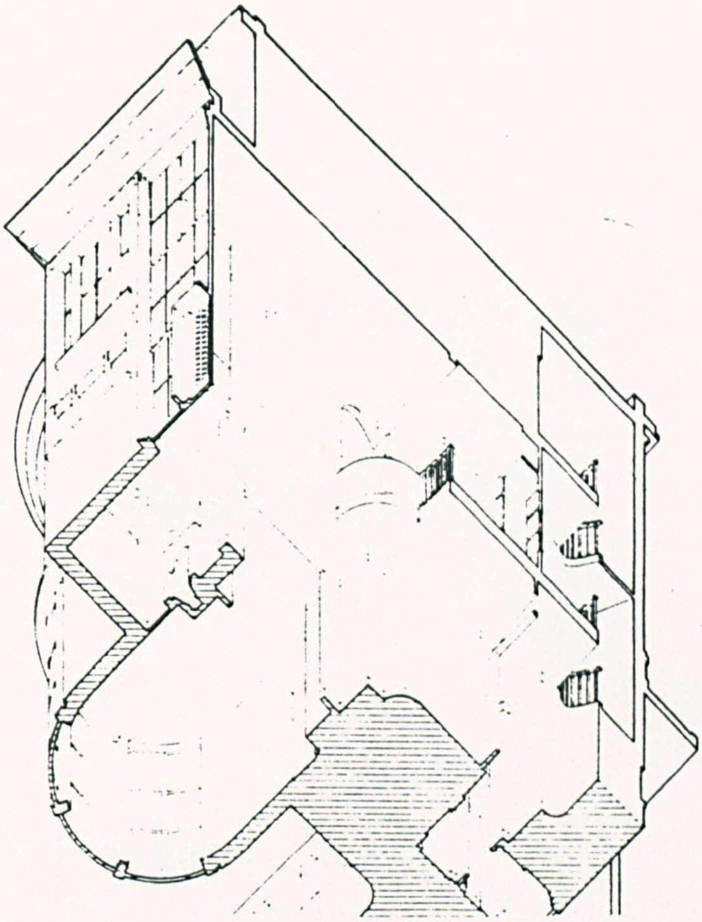


Fig. 6.1. Charles-Edouard Jeanneret, Villa Schwob, La Chaux-de-Fonds, Switzerland (1916-17), cutaway of double storey living room.

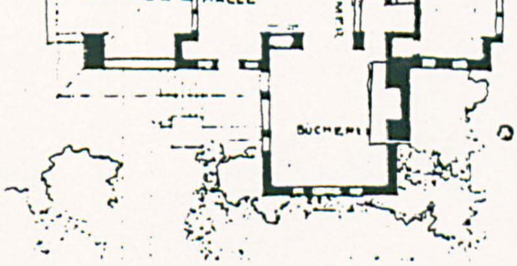


Fig. 6.2. F. L. Wright, Martin House, Buffalo, NY (1904), plan.

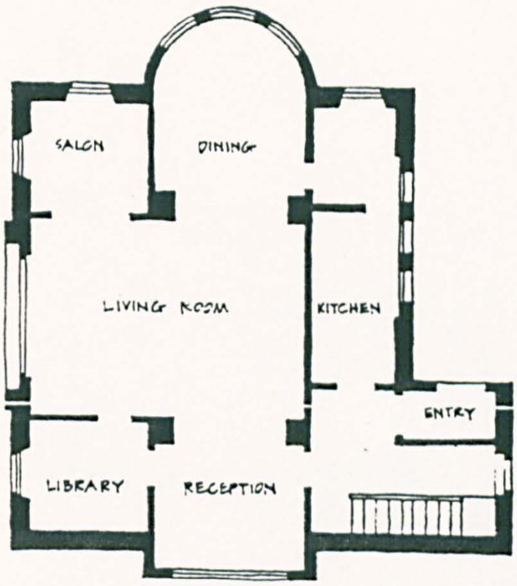


Fig. 6.3. Charles-Edouard Jeanneret, Jeanneret House, La Chaux-de-Fonds (1912-13), plan.

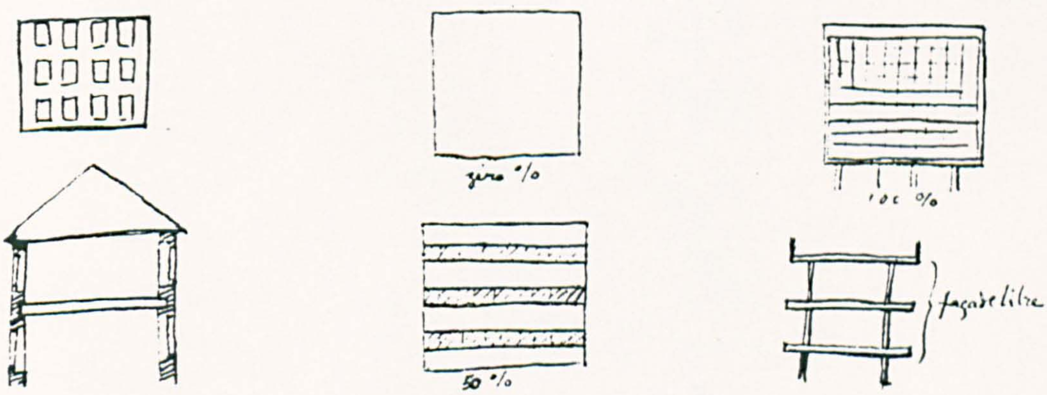


Fig. 6.4. Le Corbusier, The facade and the framework in his Five Points.

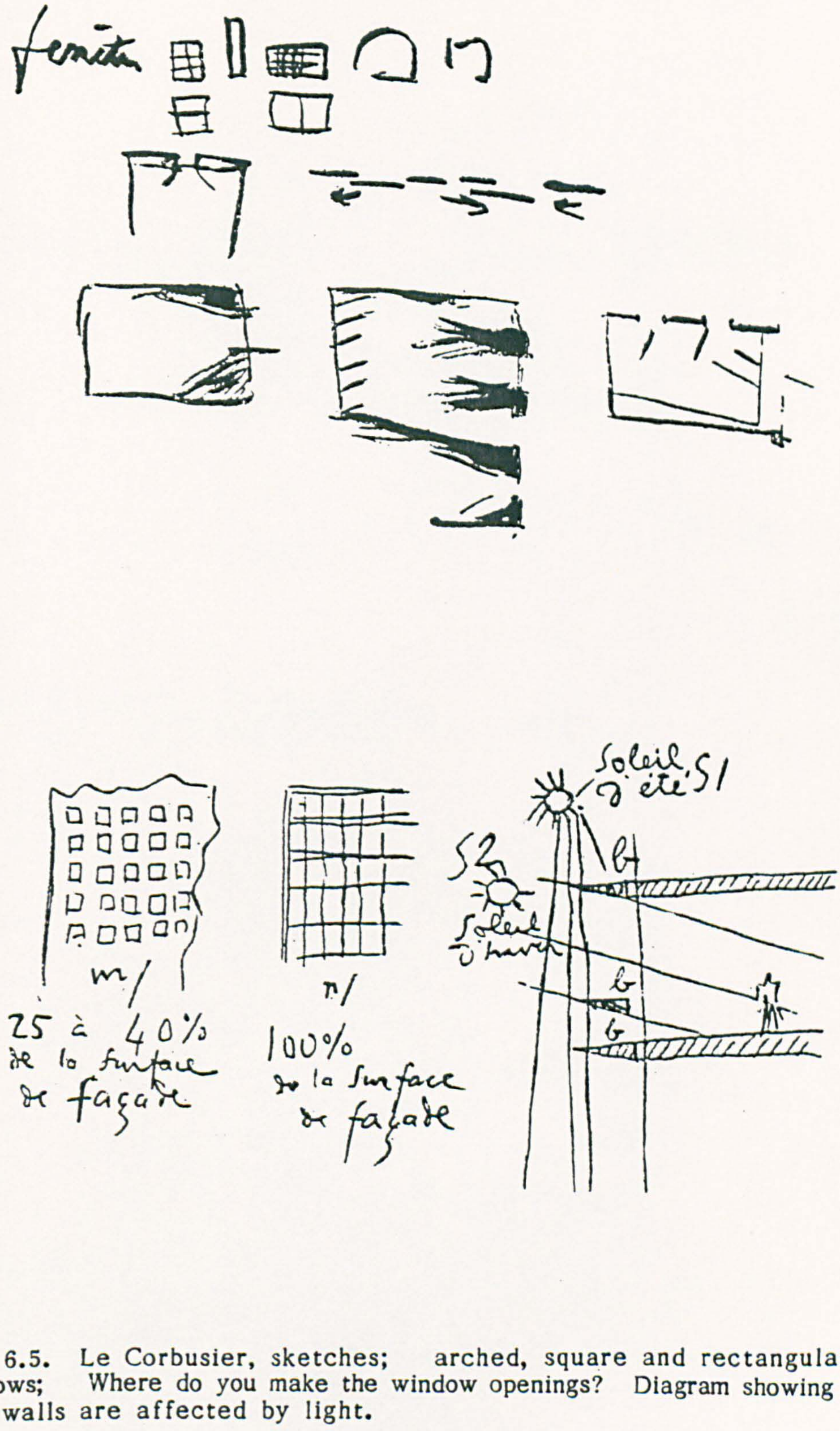


Fig. 6.5. Le Corbusier, sketches; arched, square and rectangular windows; Where do you make the window openings? Diagram showing how walls are affected by light.

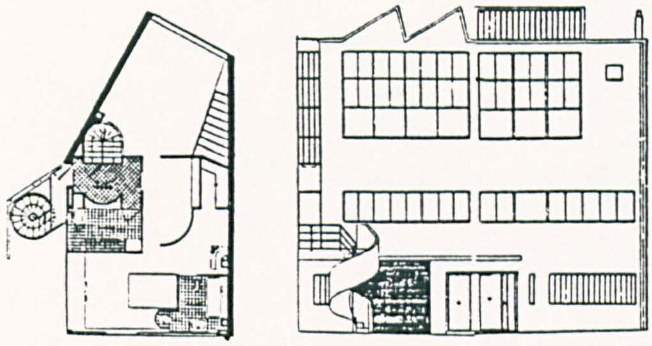


Fig. 6.6 Le Corbusier, Villa La Roche - Jeanneret; (left) plan; (right) Two facades projected onto one plane.

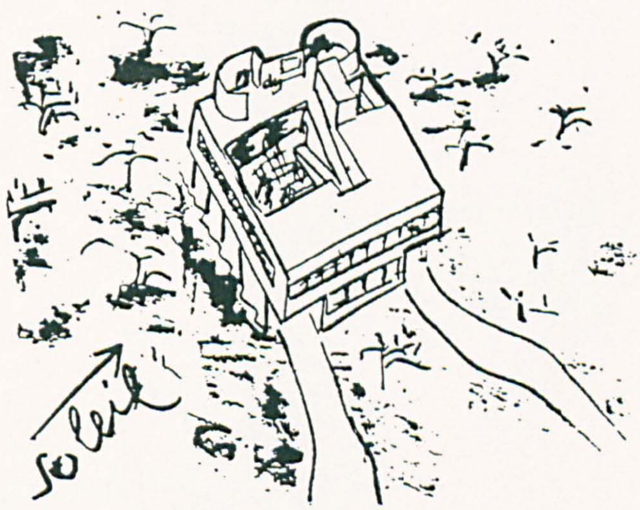


Fig. 6.7. Le Corbusier, sketch of Villa Savoie, Poissy (1929-31), showing the sun's relationship to the site.

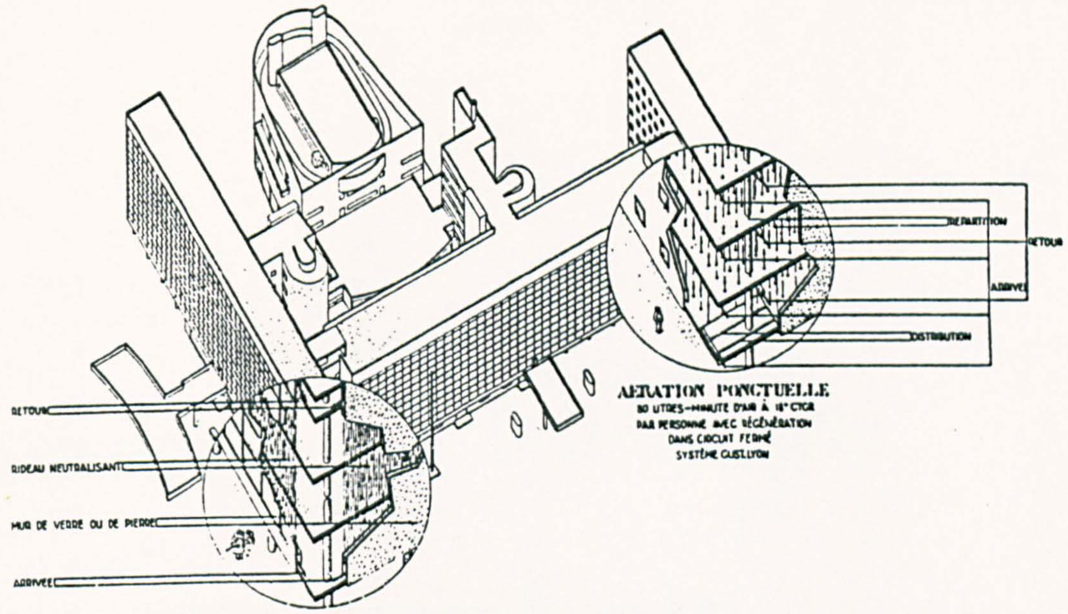


Fig. 6.8. Le Corbusier, Centrosoyus, Moscow (1929 - 33) with mechanical system contrived with the assistance of Gustave Lyon; cutaway showing the imaginary operation of the 'aeration ponctuelle' system of winter and summer conditioning by closed - circuit constant delivery of '80 litres per minute of air at 18° C for each person.

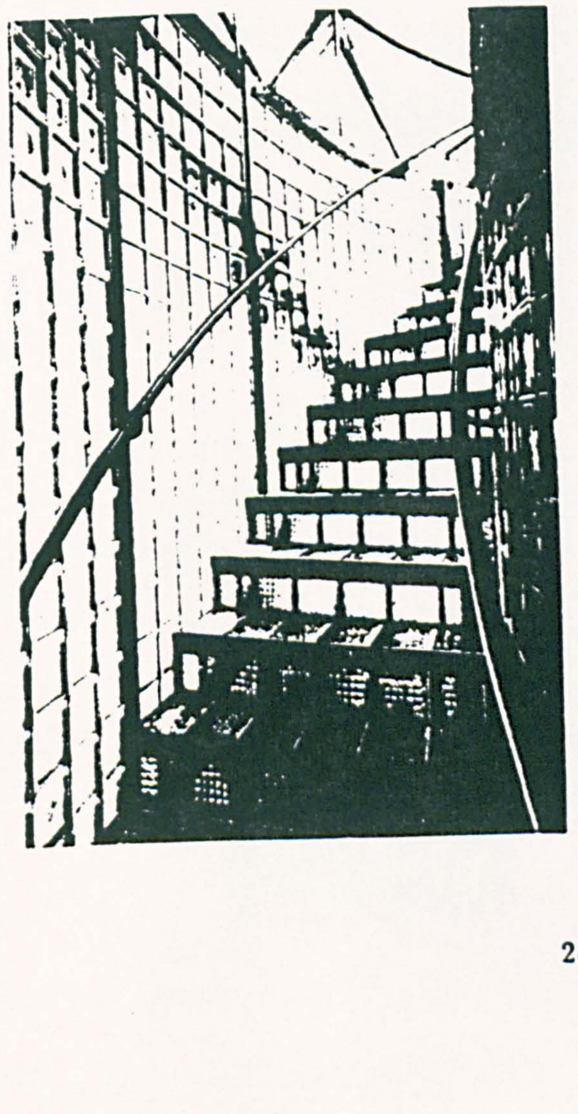


Fig. 6.9. Bruno Taut,Deutsche Werkbund Exhibition, Glashaus, Cologne, 1914. The glass walls were manufactured by the German Luxfer Prismen Organization.

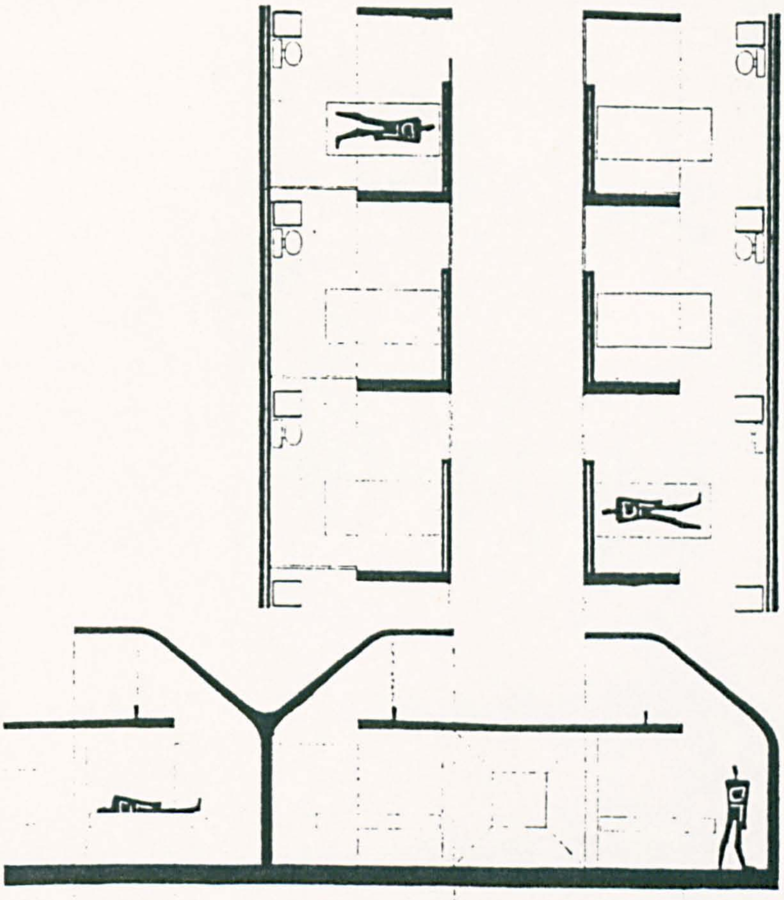


Fig. 6.10. Le Corbusier, Venice Hospital Scheme, 1965.

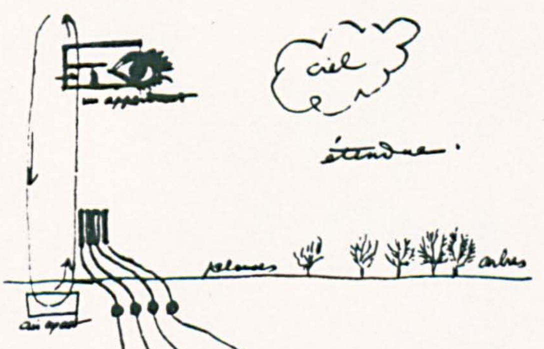


Fig. 6.11. Le Corbusier, diagram showing the delivery and distribution of services to a flat located in a high-rise building. Telephone, gas, electricity, water and conditioned air are provided for as well as exposure to the natural elements, the sky, the trees, the grass. [La Ville Radieuse, 1933]

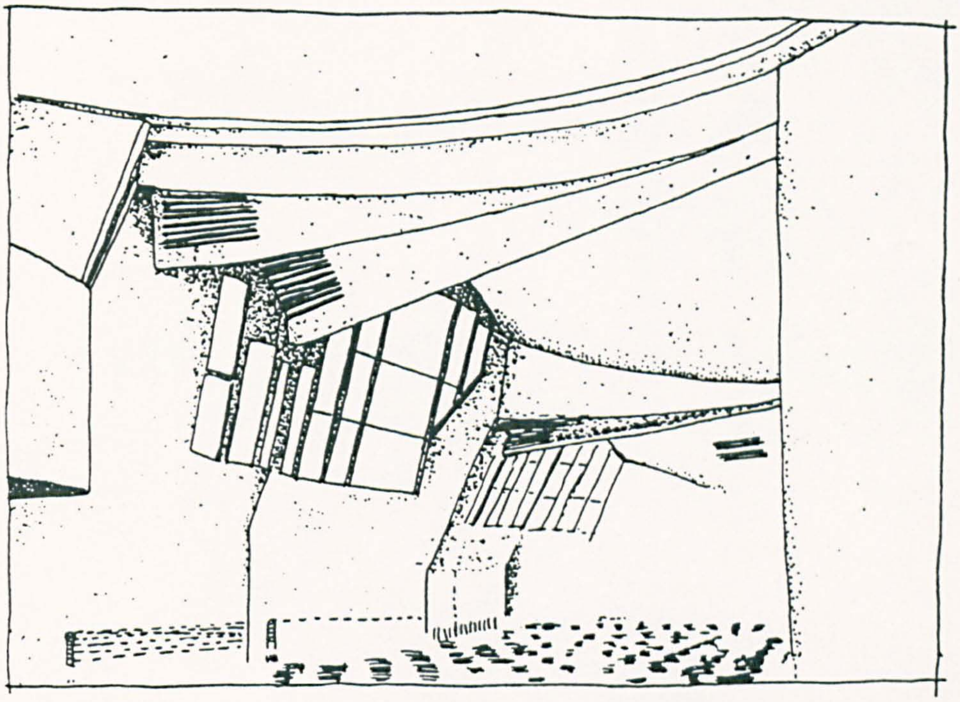


Fig. 7.1. Alvar Aalto, Church, Vuoksenniska, (1956-58). Juncture between sliding door, windows, heating and ventilation equipment expressed by folding of ceiling skin in the third compartment of the nave. Onomatopoeia is seen in the ventilation grilles in the shape of a fish's gills and the pilaster housing the dividing partitions that alludes to a hollow tree-trunk.

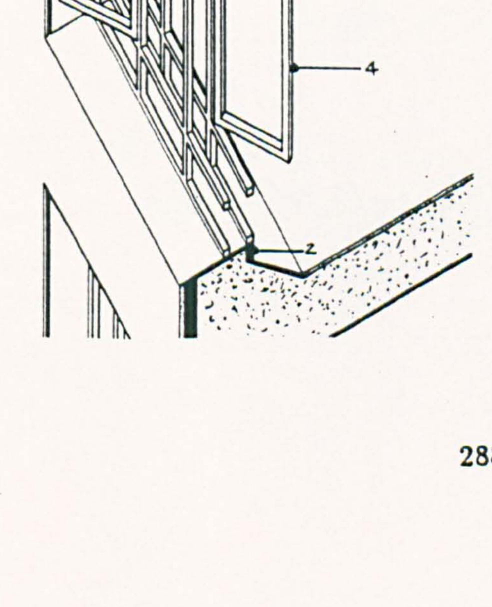


Fig. 7.2. Paimio Sanatorium, diagrammatic cutaway showing major environmental features of triple-glazed openable sash: 1. Rolling shades for sun control, insulation at night; 2. Cork insulation; 3. Double pane glazing on exterior sash; 4. Interior sash directing incoming air along side-wall of patient's room.

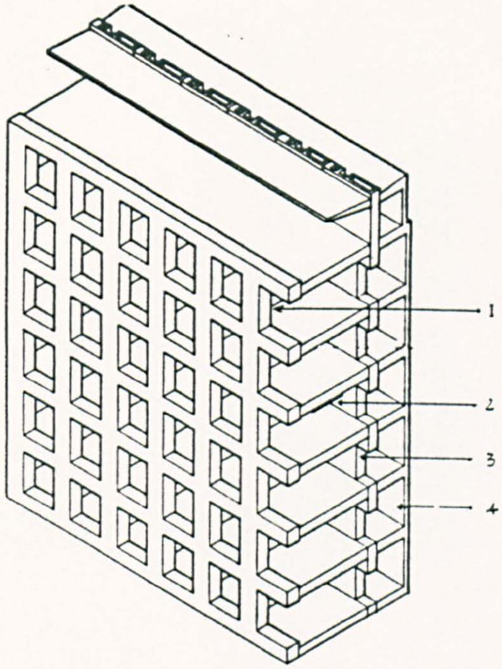


Fig. 7.3. Alvar Aalto, Paimio Tuberculosis Sanatorium (1928-33) diagrammatic cutaway showing major features:
1. Deep window jambs for triple glazing and shading;
2. Patient rooms with radiant heating panels in ceiling;
3. Service core;
4. Circulation.

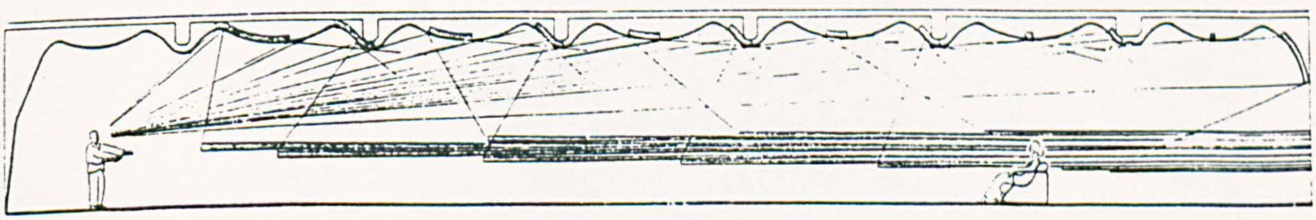


Fig. 7.4. Alvar Aalto, Viipuri Library, Finland (1927-35); interior of lecture hall during and after construction; acoustic soffit of conference hall.

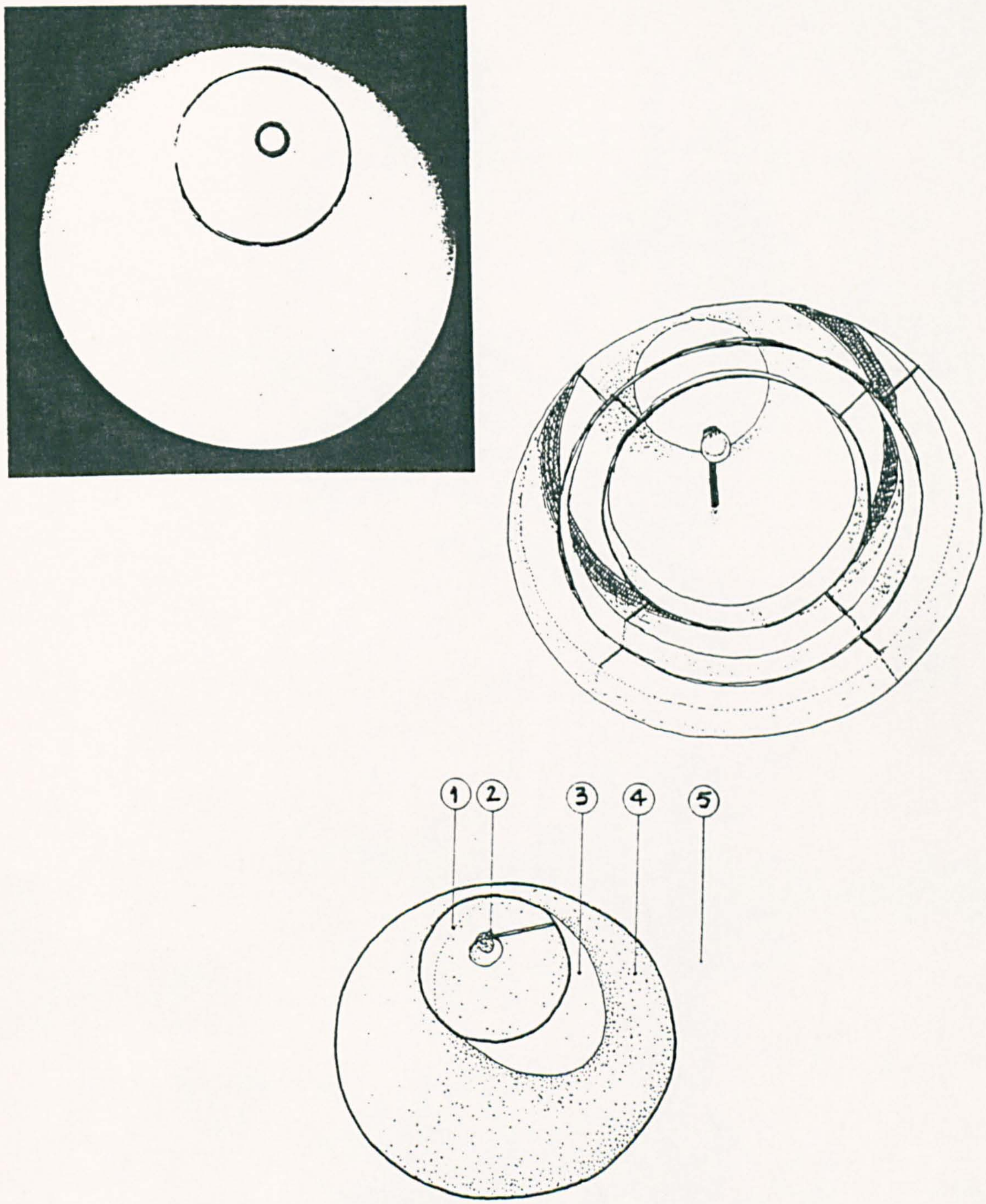


Fig. 7.5. Alvar Aalto, views and diagram of function of circular skylights showing deep, conical well which intercepts and diffuses direct sunlight. 1. line of shadow on skylight glass; 2. incandescent light for nighttime; 3. elliptical-shaped patch of sunlight on conical wall of skylight well; 4. area of reflected light in skylight well; 5. ceiling of room.

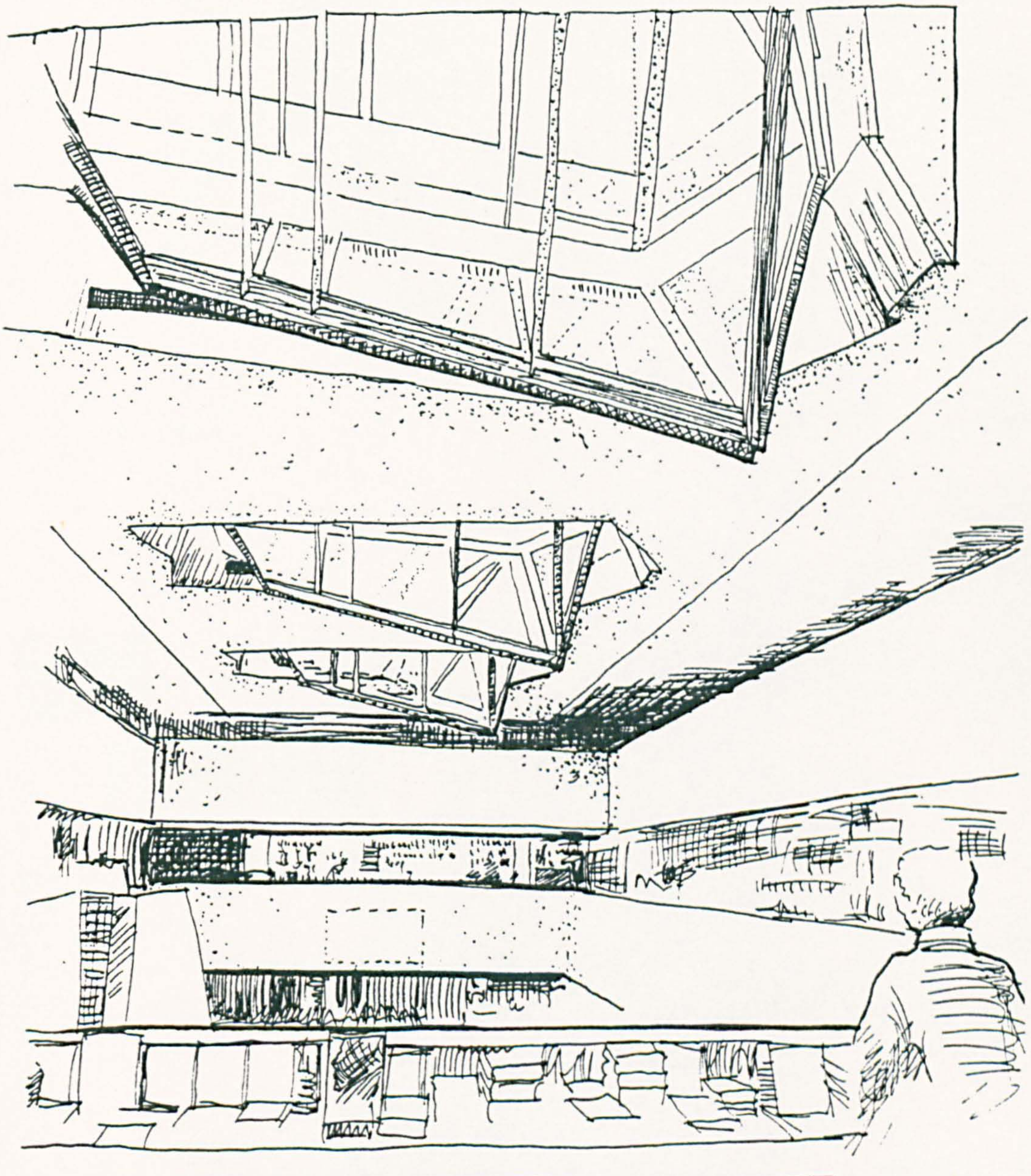


Fig. 7.6. Alvar Aalto, Academic Bookstore, Helsinki. The prismatic skylights, similar to those used at National Pensions Institute, not only penetrate up through the snow to gather light in winter but also plunge into the space below to deliver the light.

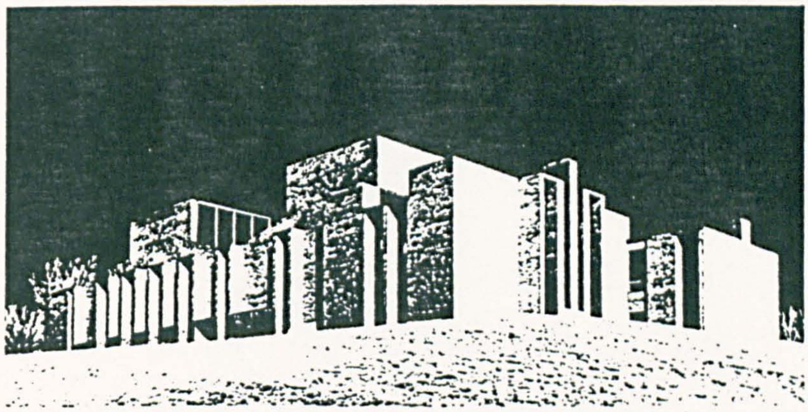


Fig. 8.1. Louis I. Kahn, First Unitarian Church, Rochester, New York (1964) view.

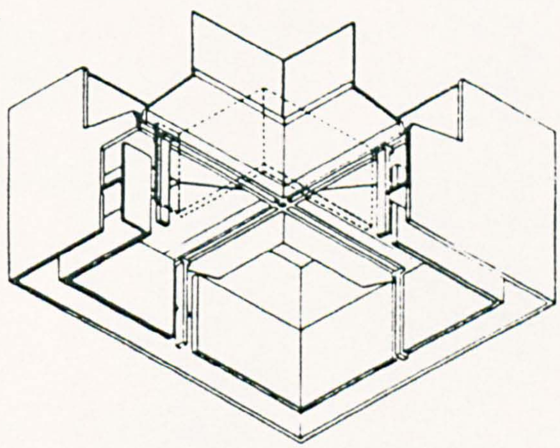


Fig. 8.2. First Unitarian church, clerestory light hood.

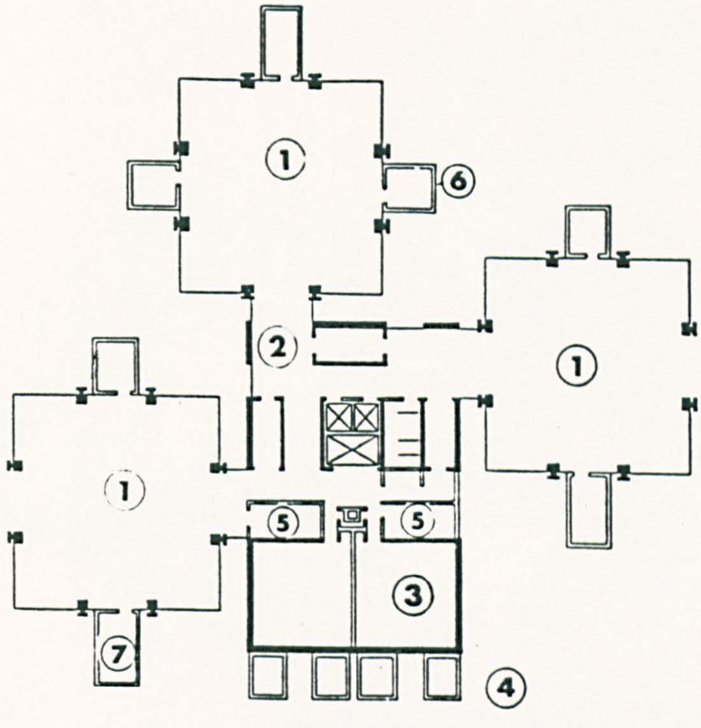


Fig. 8.3. Louis I. Kahn: Richards Medical Research Building, Philadelphia (1961-8). Typical schematic floor plan: 1. studio laboratory towers; 2. corridors and vertical circulation; 3. animal quarters; 4. shafts for outside air intake; 5. shafts for the distribution of conditioned air; 6. fume exhaust and vertical utility runs; 7. peripheral fire stairs

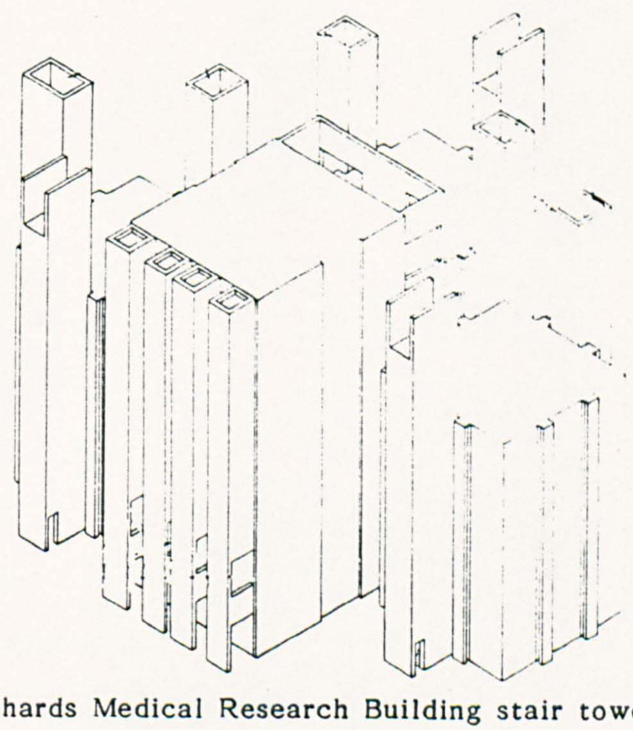


Fig. 8.4. Richards Medical Research Building stair towers, vertical slabs.

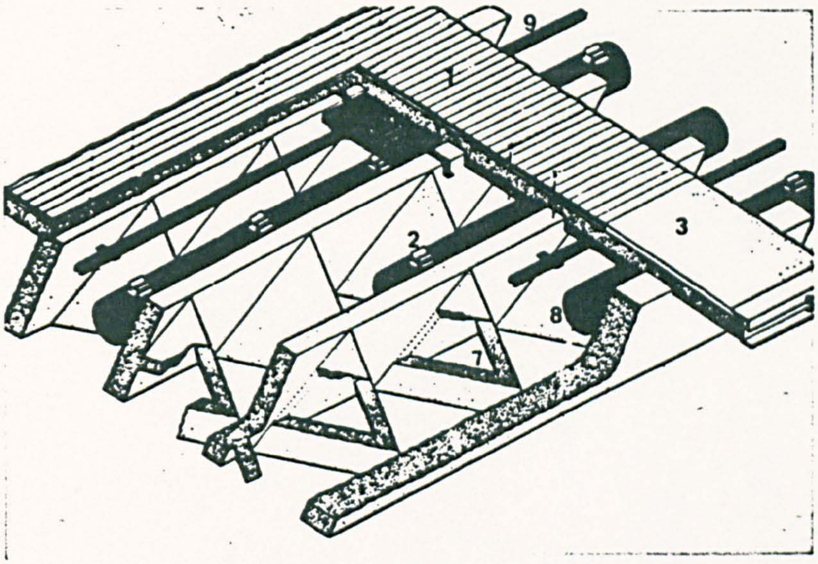


Fig. 8.5. Louis I. Kahn, Yale Art Gallery, New Haven, 1951-53, Air distribution system showing: 1. oak flooring; 2. air outlet; 3. terrazzo; 4. floor slab; 5. framing at window; 6. acoustical plank; 7. bridging, 8. continuous air distribution duct; 9. electrical raceway for adjustable lighting units.

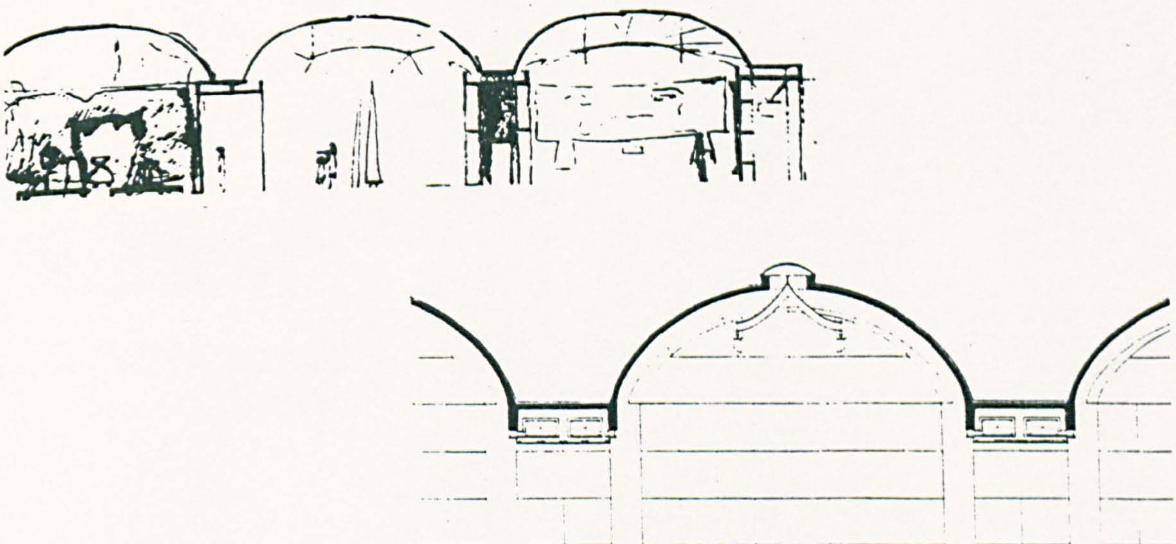
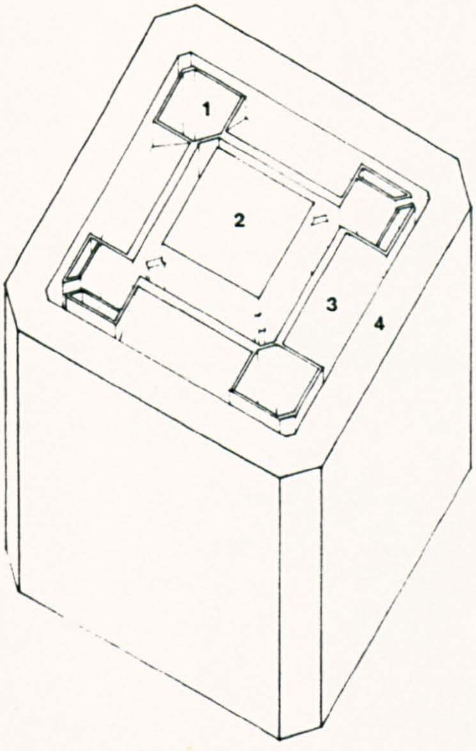


Fig. 8.6. Louis I. Kahn, Kimbell Art Museum, from early sketches to final design. Section through vaulting showing skylight with placement of perforated reflector, air ducts in marginal channel



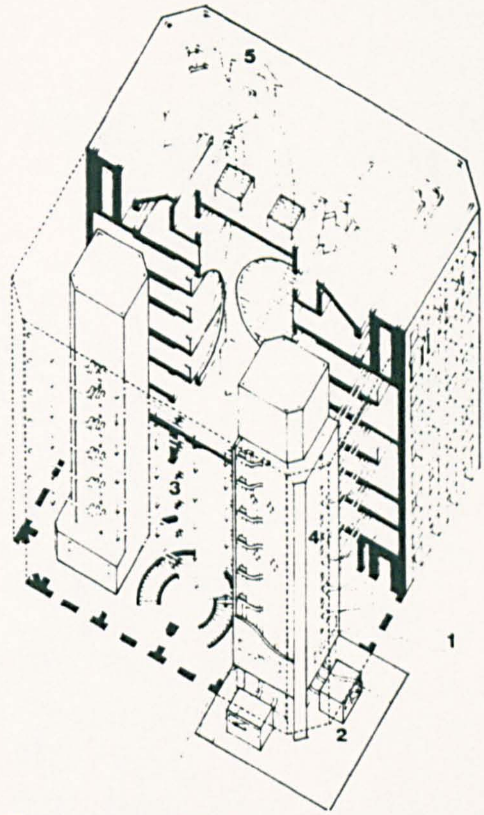


Fig. 8.7. Louis I Kahn, Library, Phillips Exeter Academy, massing and allocation of major forms.

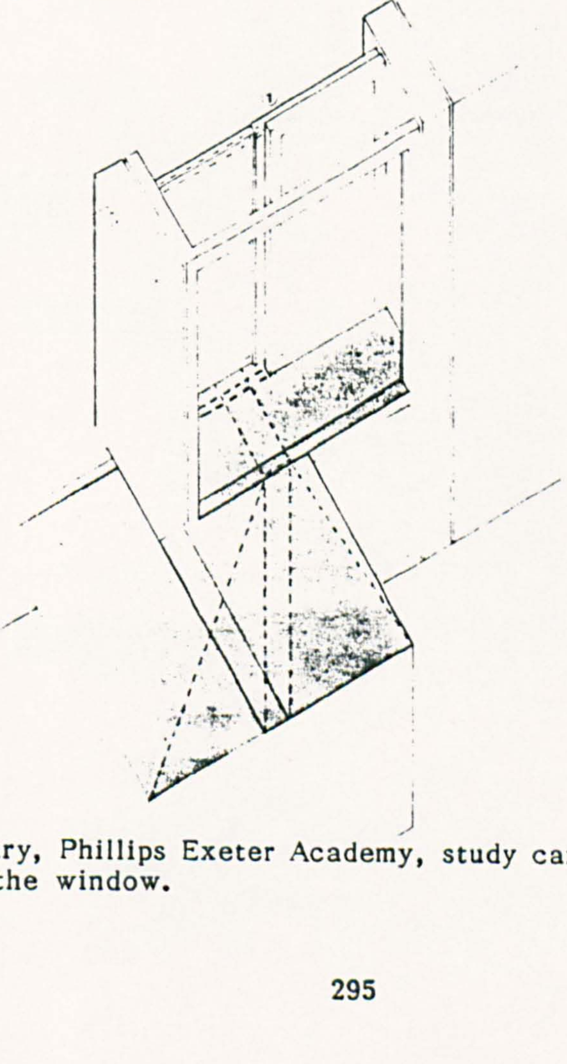


Fig. 8.8. Library, Phillips Exeter Academy, study carrel and relationship to the window.

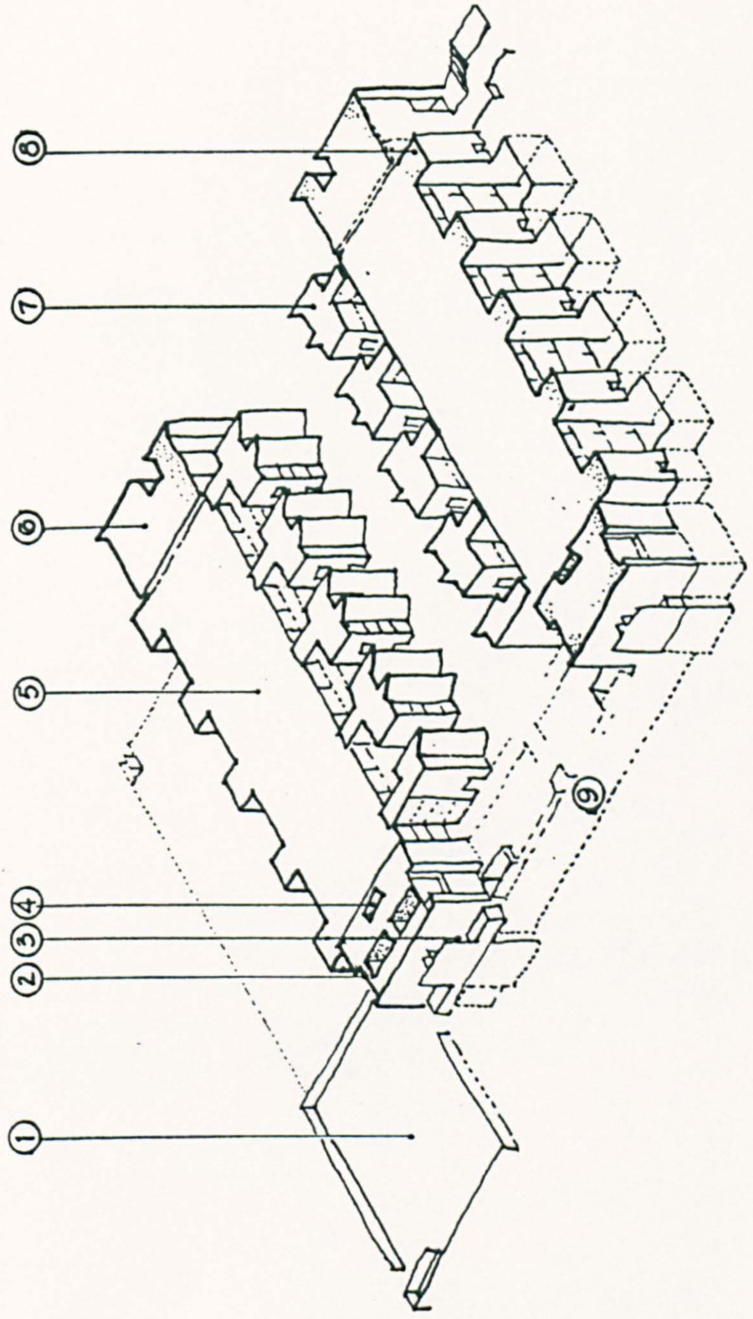


Fig. 8.9. Louis I. Kahn, Jonas Salk Insititute, La Jolla California, 1965: 1. Service yard; 2. Cooling tower; 3. Air intake; 4. Exhaust; 5. Laboratory Block; 6. Administration wing; 7. Study Tower; 8. Service tower; 9. Mechanical Room.

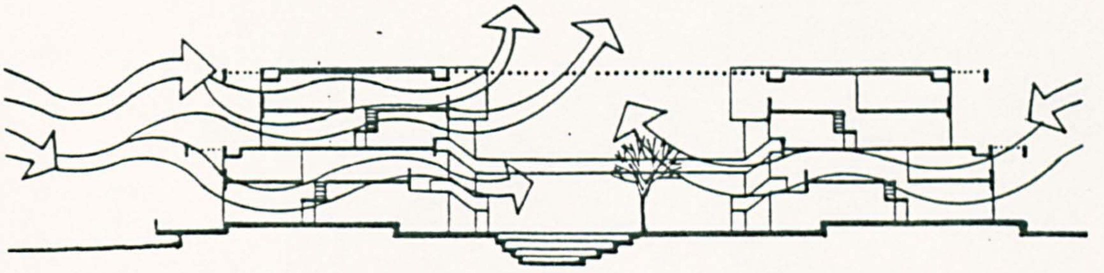


Fig. 9.1. Charles Correa, design for the capital complex for Emperor Akbar at Fateh-pur-Sikri. The design makes use of a pattern of open pavilions, placed formally in the context of courtyards, inlaid with fountains and running water.

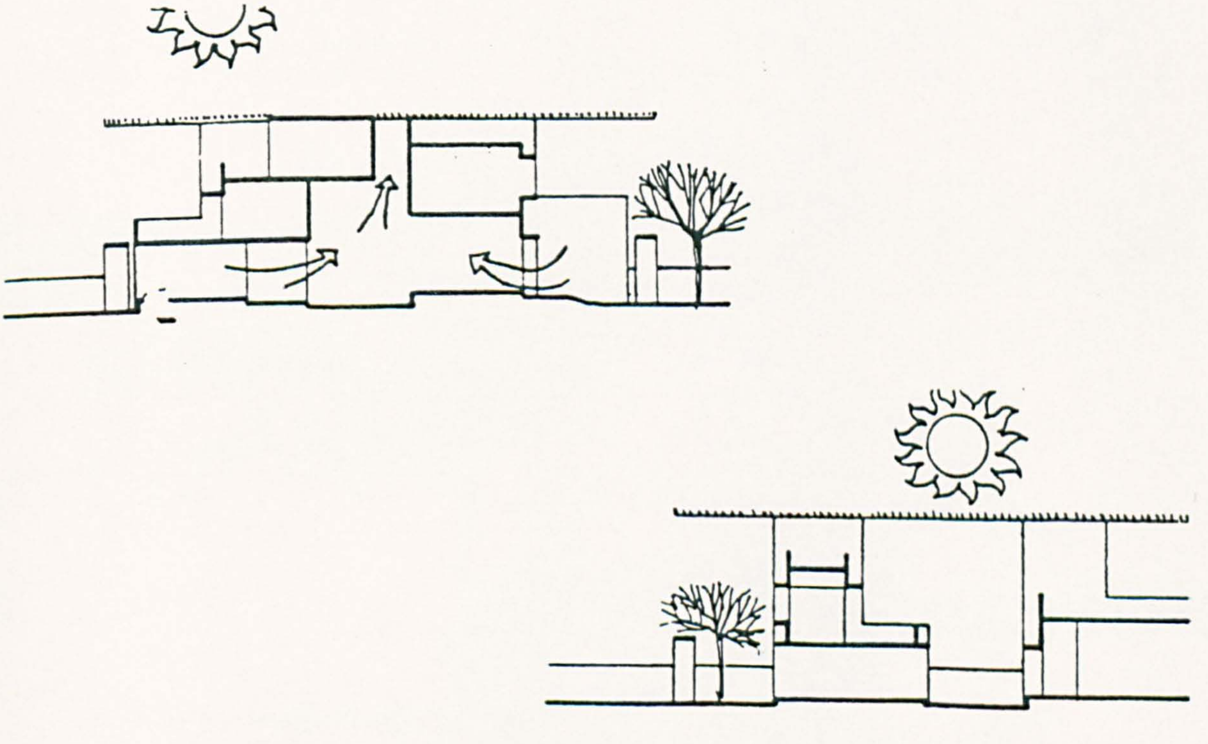


Fig. 9.2. Charles Correa, design for a series of narrow rowhouses which provide for changing patterns of use from one season to the next. Shown are two basic sections; above left, a 'summer section' which creates a pyramidal interior space by closing off the sky. Below right, a 'winter section,' which is a reverse pyramid, opening up to the sky for use in the cold season and in the summer evenings.

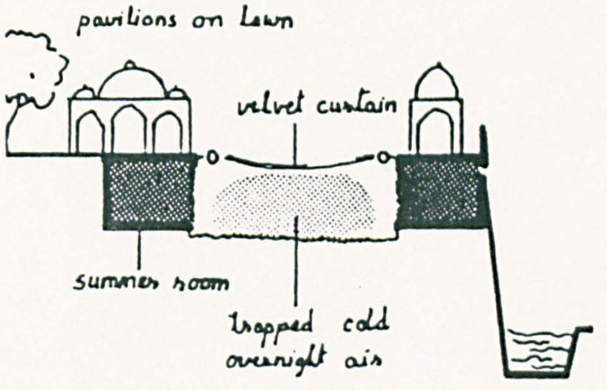


Fig. 9.3. Charles Correa, diagram of the design for the Agra Fort. During the summer months a velvet curtain is stretched across the courtyards in the early morning, trapping the cold night air in the lower level of rooms. In the evening, the awning is removed. In the cold winter, the pattern is reversed: the terrace garden is used during the day, and courts and lower levels at night.

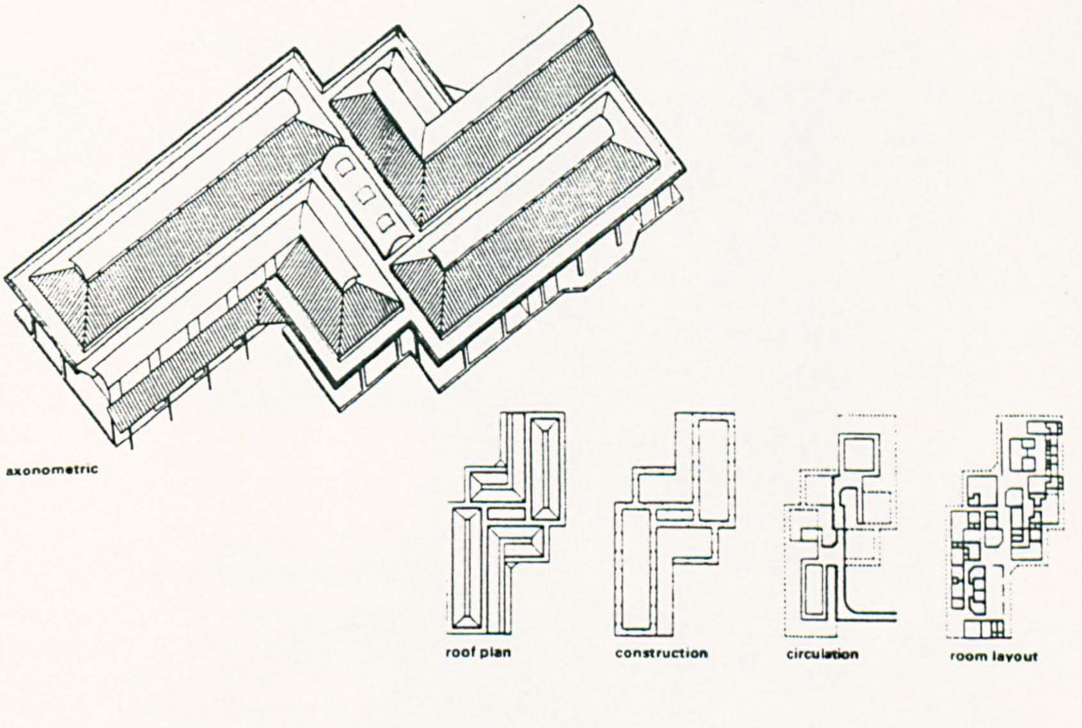
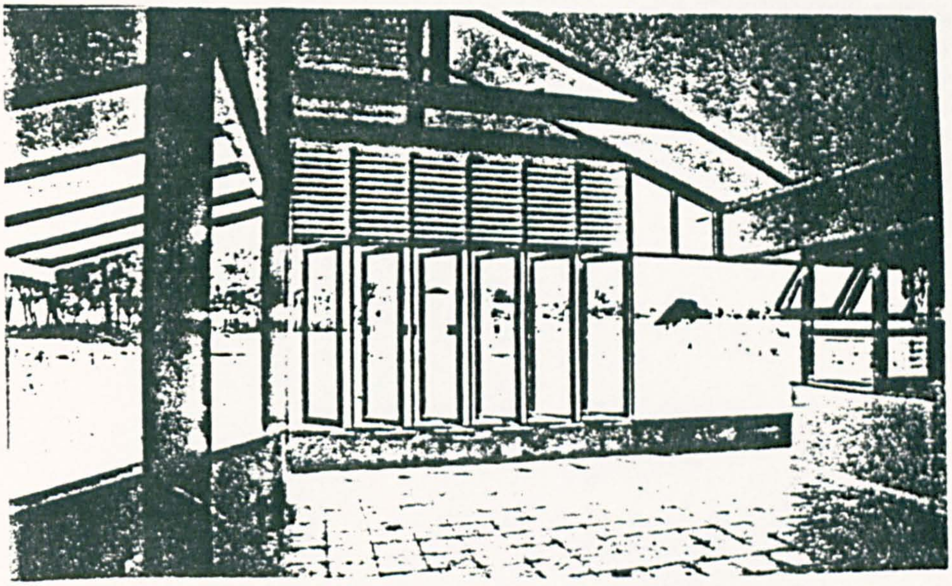


Fig. 9.4. Lucien Lafour, The Marienburg Health Center, near Paramaibo, Surinam built on a former plantation across the Surinam River from Paramaibo. Upper left, external form; lower right, plan diagrams.



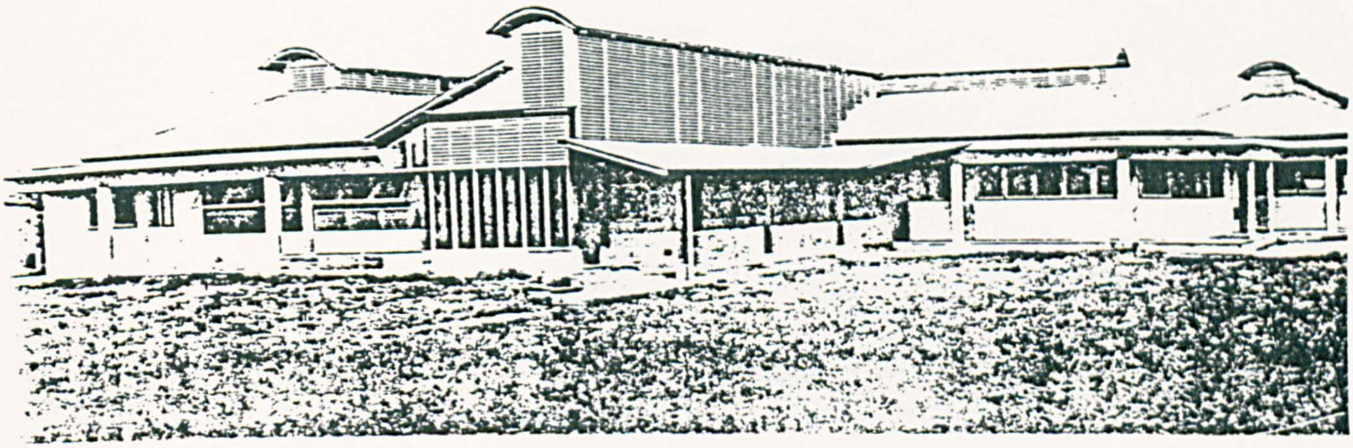


Fig. 9.5. Lucien Lafour, Marienberg Health Center. The design achieves comfortable internal conditions by exploiting the climate to maintain constant air movement. An east-west orientation lessens the amount of sunlight beating on wall surfaces and draws in the prevailing northeast breezes. Heavily insulated, pitched, overhanging roofs shade the walls from the direct overhead sun in the east and west elevations, providing shade and shelter. Vertically pivoted windows and a double bank of louvres act as ventilating monitors along the elevated ridges of the roof. Ceilings of public areas slope up to the ventilators, while internal rooms have flat ceilings.

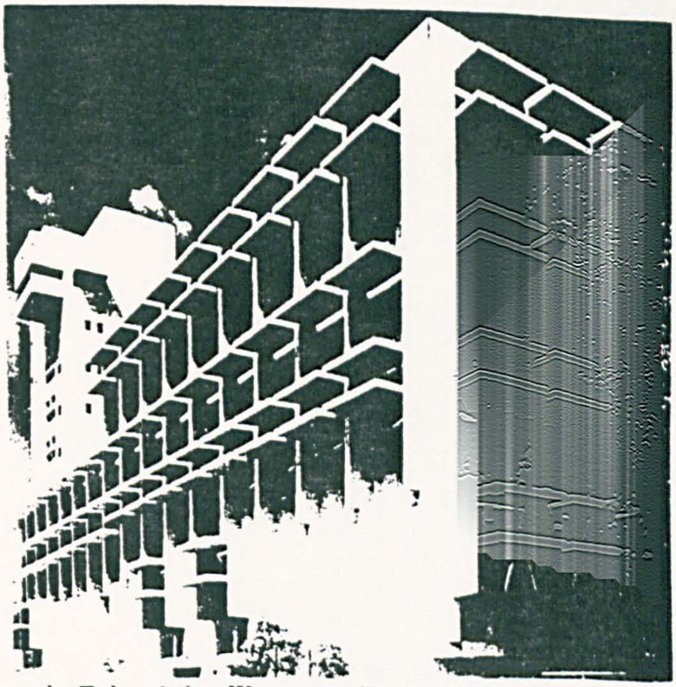


Fig. 9.6. Joseph Esherick, Wurster Hall, University of California at Berkeley.

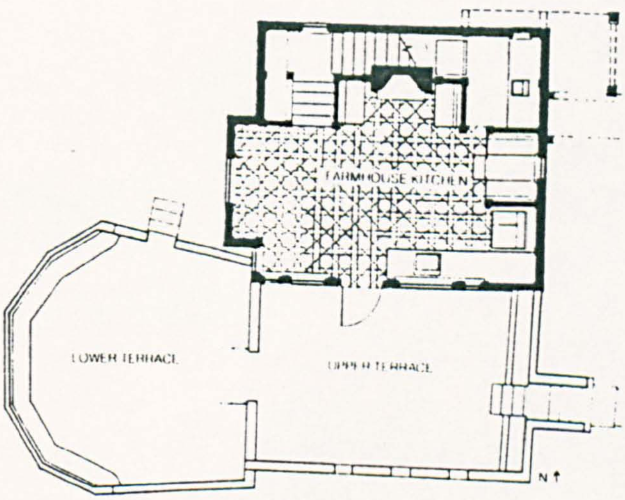


Fig. 9.7. Christopher Alexander, Sala house in Albany, California. Plan of ground floor. Shown are the thick walls and sturdy columns, inglenook, alcoves, and windows.

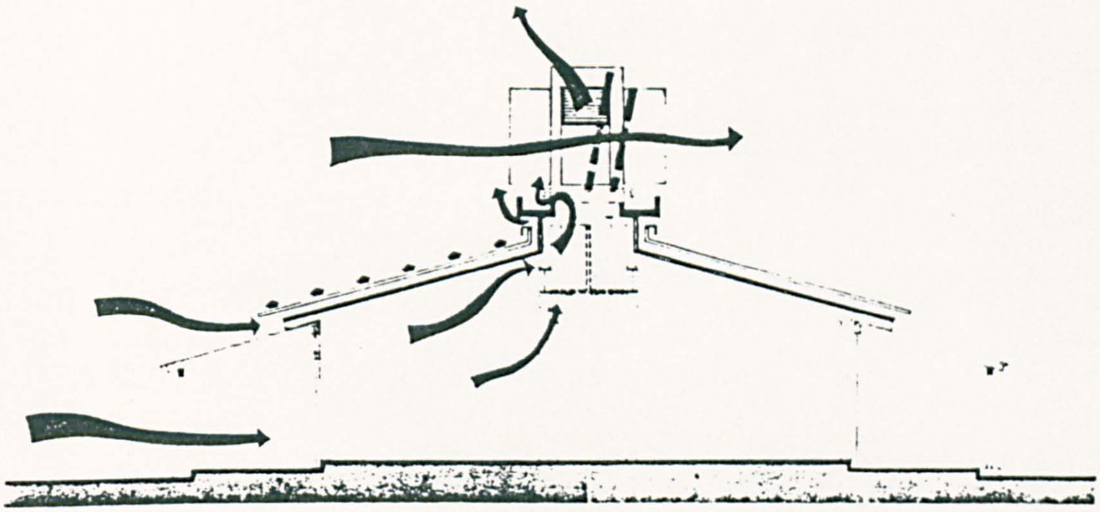


Fig. 9.8. Arup Associates, Project for the School of Mining in Jos, Nigeria, 1978. Section through classrom showing ventilation by naturally induced air flow.

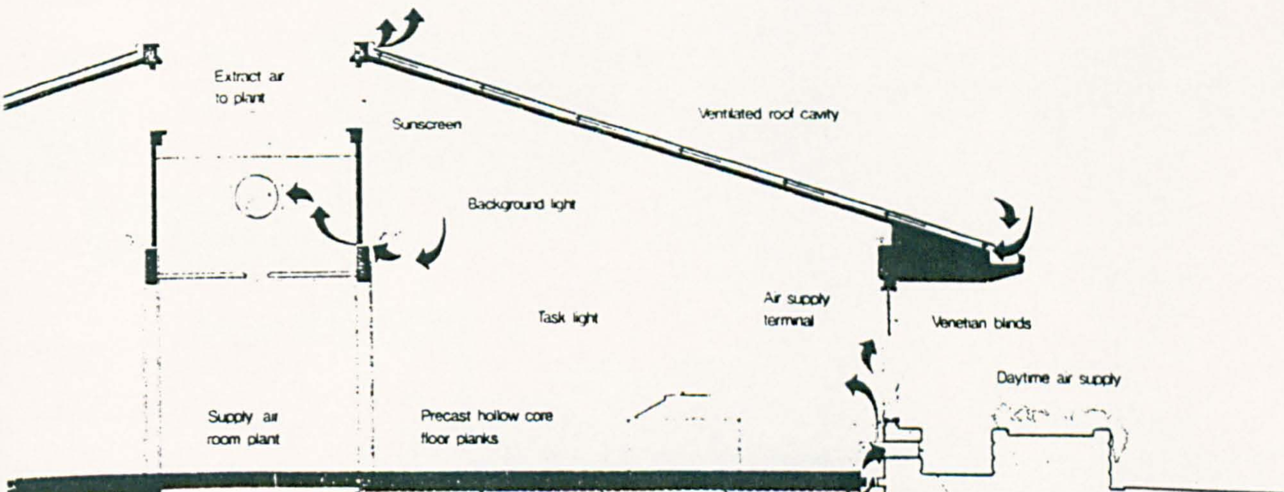


Fig. 9.9. Arup Associates, South West Regional Headquarters of the Central Electricity Generating Board in Bristol, 1978. Section through typical office showing integration of environmental features: Precast hollow core floor planks carry air supply and night cooling air discharge to the exterior.

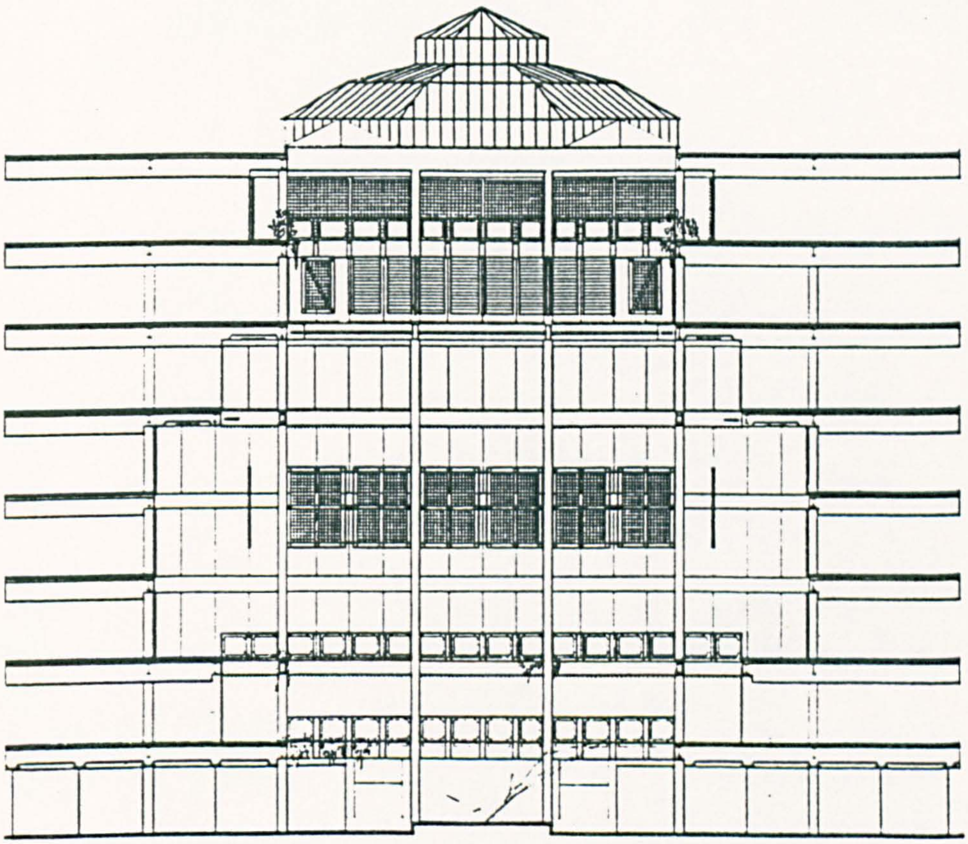


Fig. 9.10. Arup Associates, Office Building, London. Constant width floors step back from the perimeter at the upper levels as they step into the atrium. The main facade of the building appears to be only five storeys, which matches the height of the neighbouring buildings.

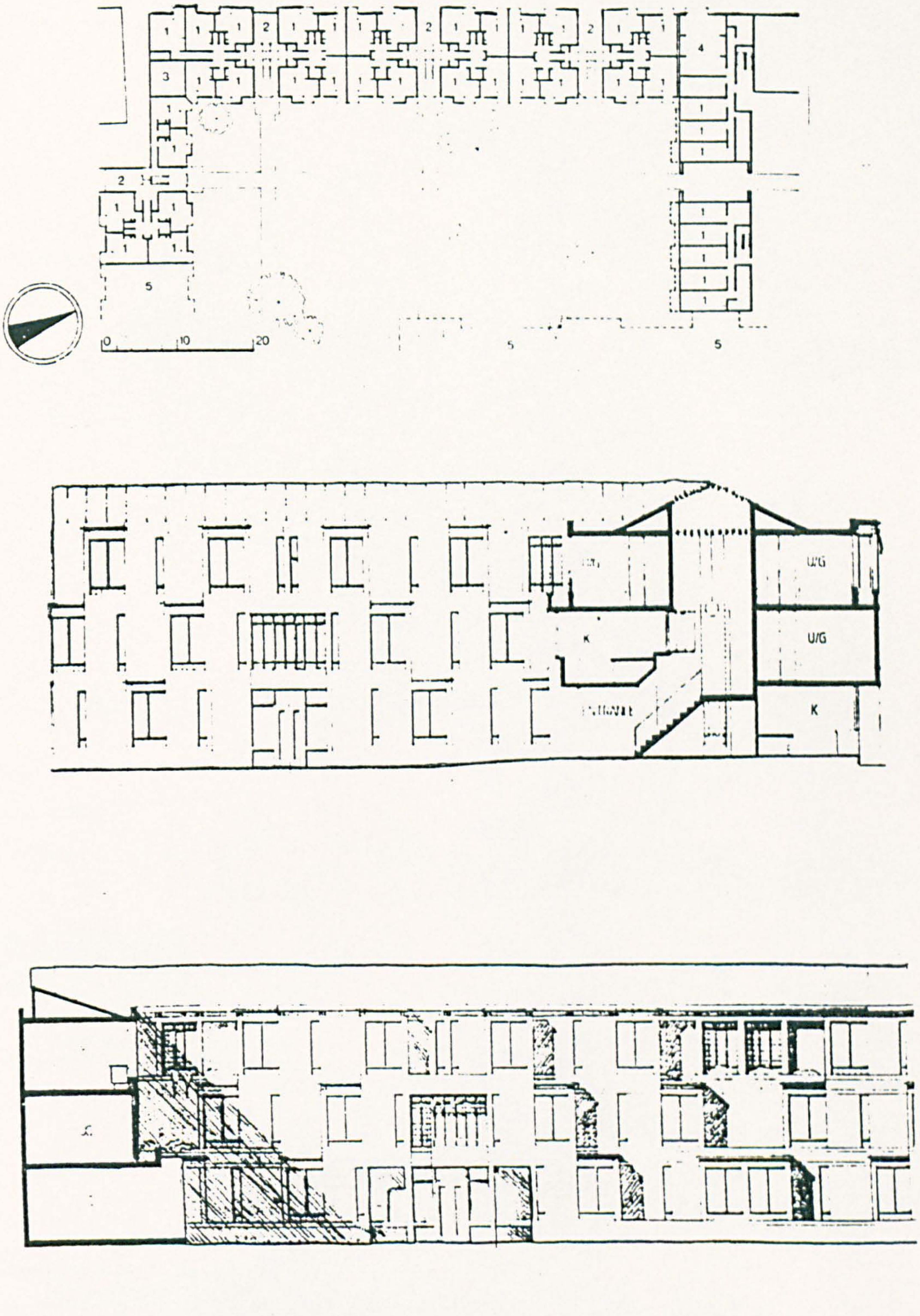
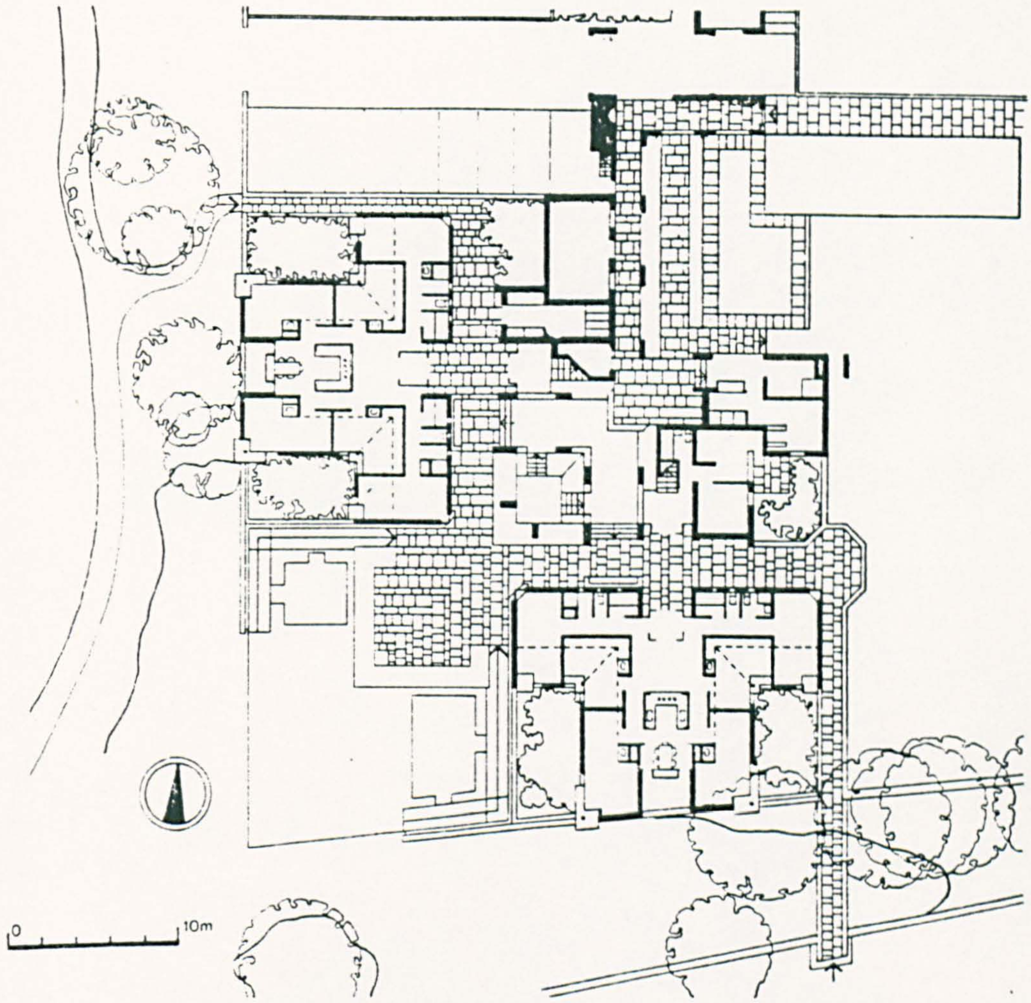


Fig. 9.11. MacCormac, Jamieson and Prichard, Fitzwilliam College, Cambridge. Above, plan. Middle, section through stair. Below, early facade studies. The rooms are clustered around shared spaces, with a staircase hall which is a double-height top-lit space. Soanian effects are achieved with a glass frieze [A.J. 30 May 1984 p.20]



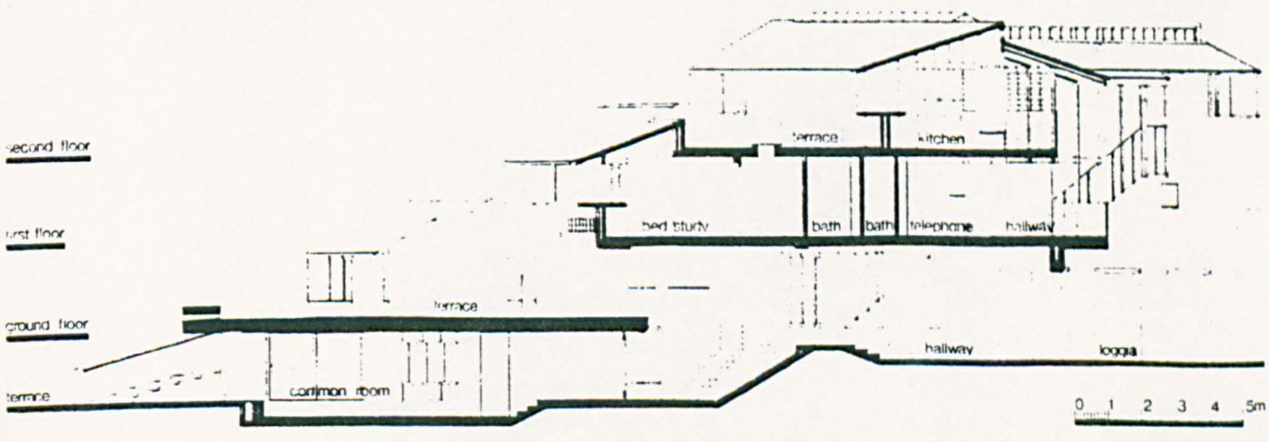


Fig. 9.12. Richard MacCormac, Sainsbury building, Worcester College, Oxford. Above, Plan; Below, diagonal section, south-west to north-east, showing terraced layout of bedrooms/studies.

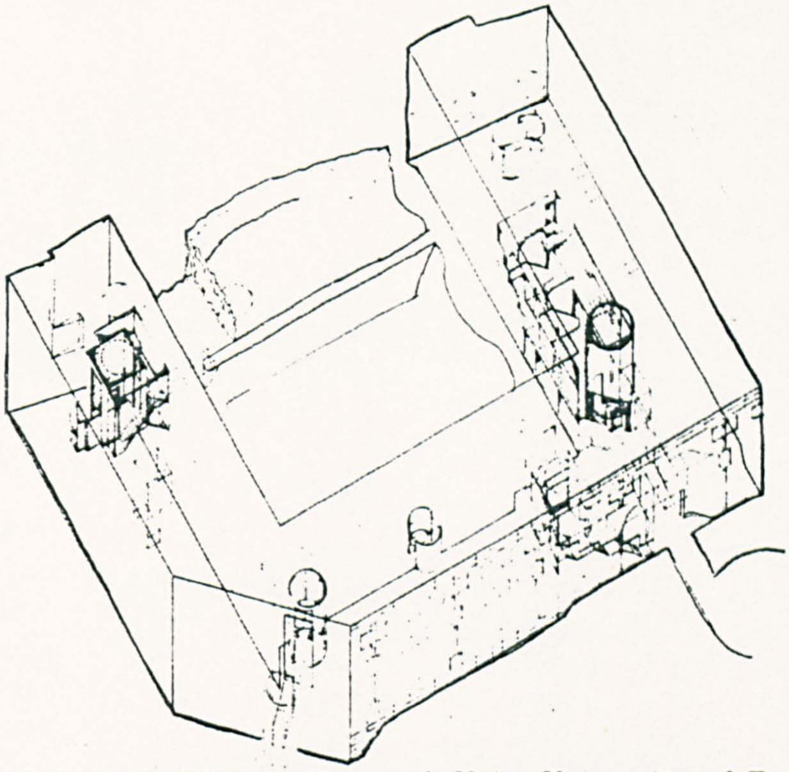


Fig. 9.13. Rick Mather, Climatic Research Unit, University of East Anglia. Axonometric looking north-west, showing the internal organisation.

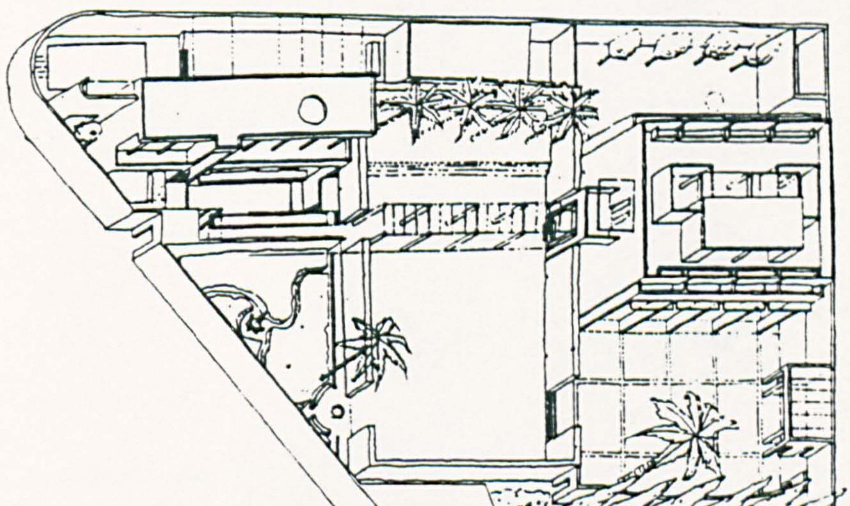


Fig. 9.14. Rick Mather, houses in Khartoum, sketch. The volumes are kept simple, but two facades in each case (the north and south) are highly articulated. East and west walls are entirely flush. The interiors, punctuated by round columns, are complex and free-flowing spaces which allow through-draught.

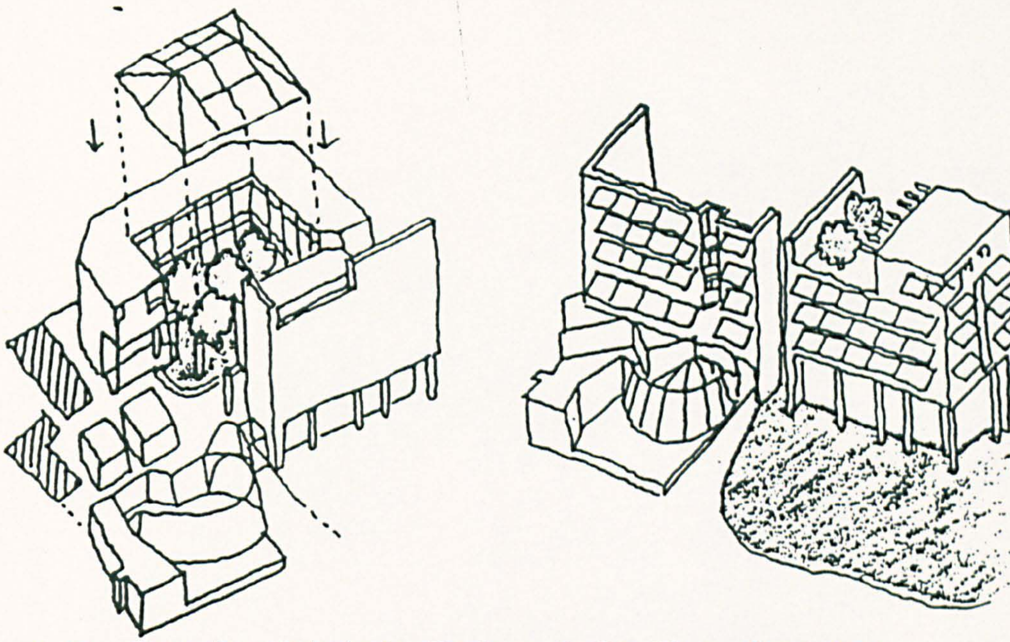


Fig. 9.15. Guenther Behnisch, Herbert Keller Haus, Stuttgart. Sketch studies by Richard Reid. Left, the building is seen from the entrance, showing the central atrium. Right, facade of main block, enlivened with sunshades.

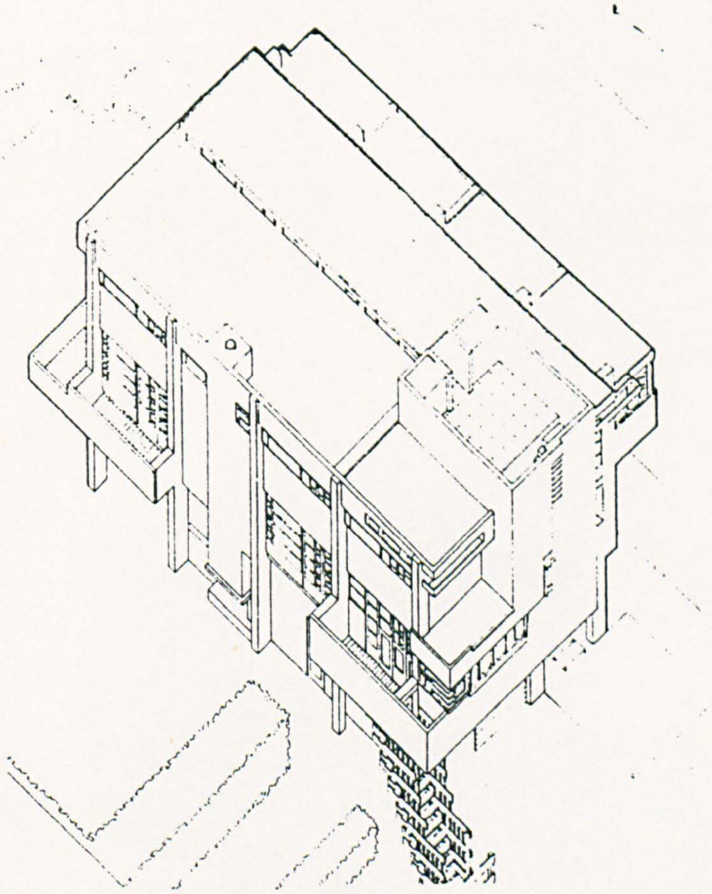


Fig. 9.16. Rudolf Schindler, Lovell Beach House (1921-1926). Axonometric cutaway drawing, showing light, airy nature of structure and cladding. [Oppositions, 1979]

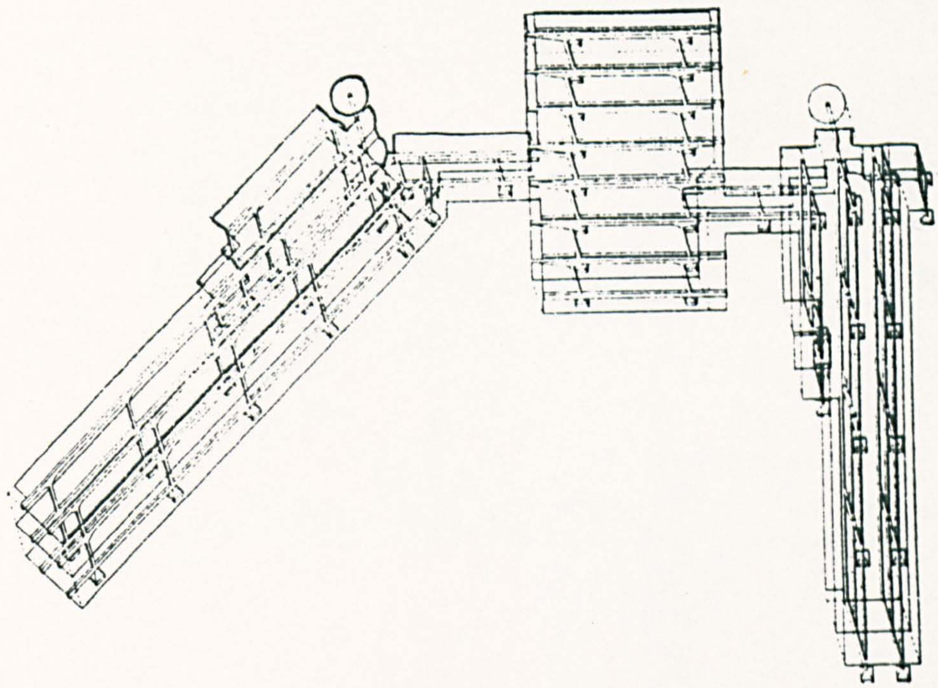


Fig. 9.17 Jan Duiker, Zonnestraal Sanatorium (1928) axonometric of structural framework.

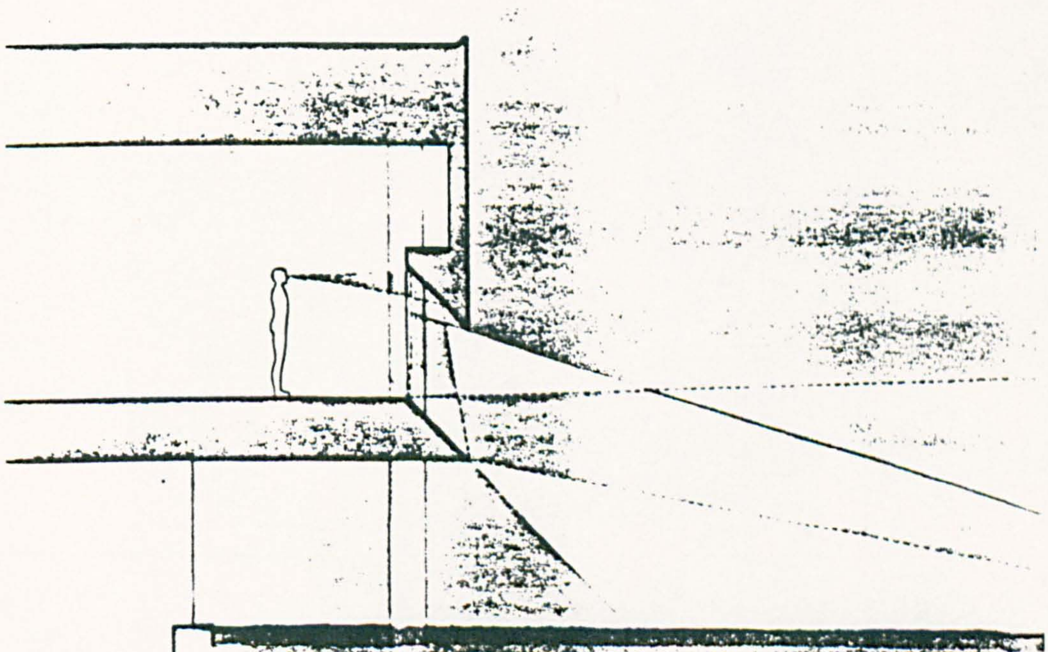


Fig. 9.18. Gunnar Birkerts, Corning Museum of Glass, Corning New York. Diagrammatic section through the glass curtain wall. Direct sun is cut off and distant views are simultaneously reflected inside. Birkerts refers to this detail as a "periscope"

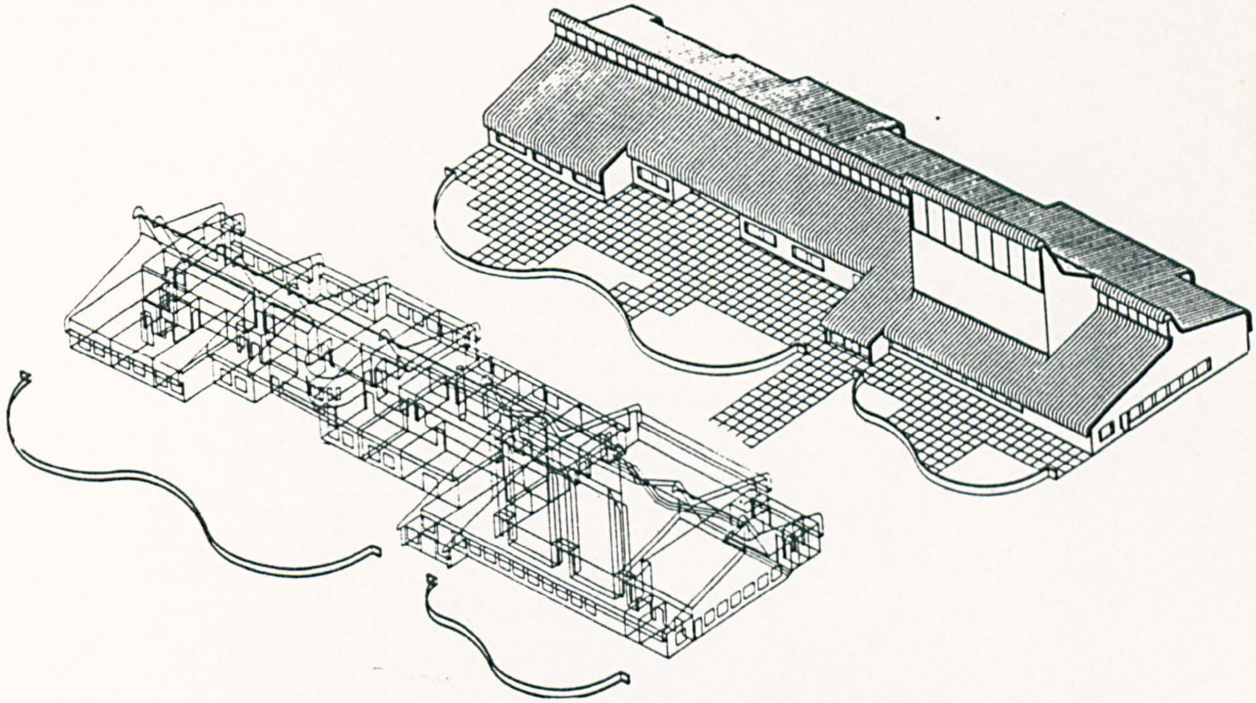


Fig. 9.19. Birkerts, Religious Centre in Frankfurt, Aalto's forms and use of materials are evoked here. Left, spatial diagram. Right, exterior form.

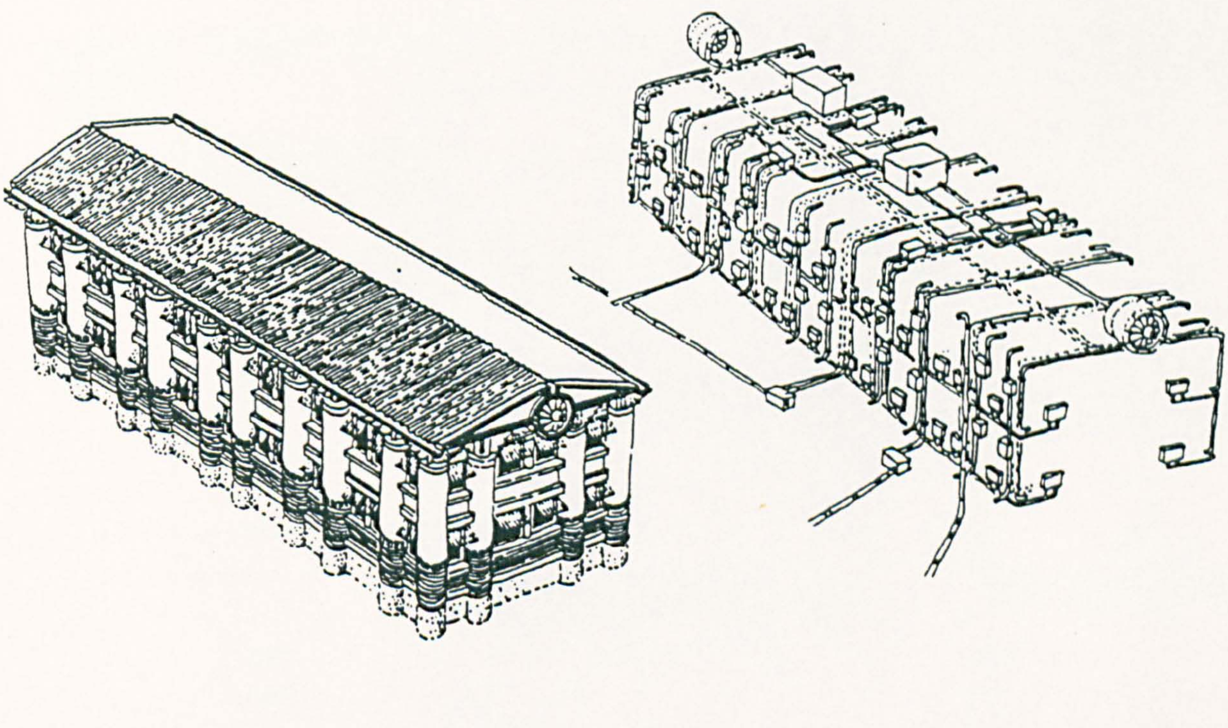


Fig. 9.20. John Outram, office remodel for a heating company in Swansey, Kent. Left, hard-shell external form. Right, services.

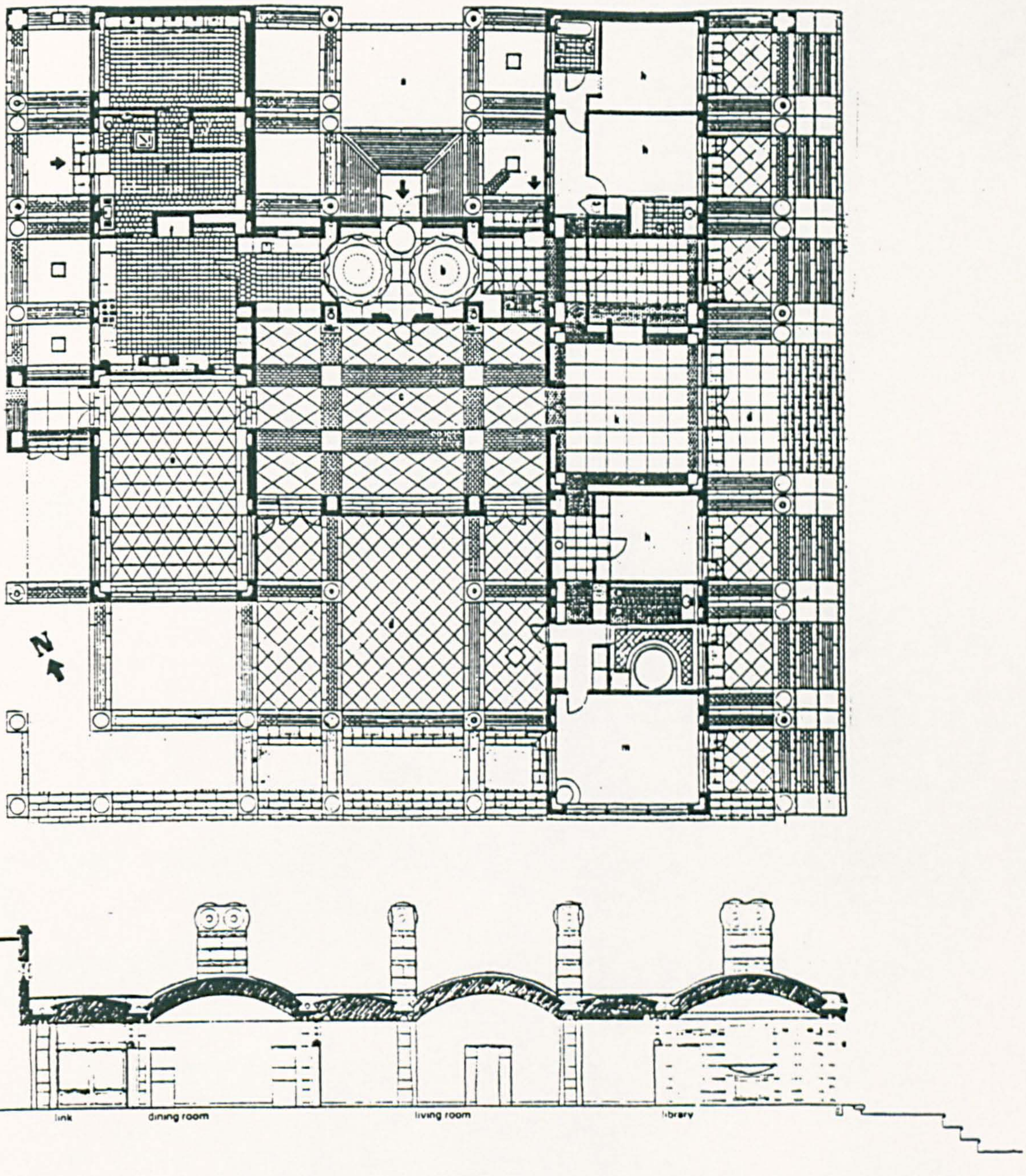


Fig. 9.21. John Outram, country residence, southern England. Above, plan. Below, section through east-west centre line of house looking north.

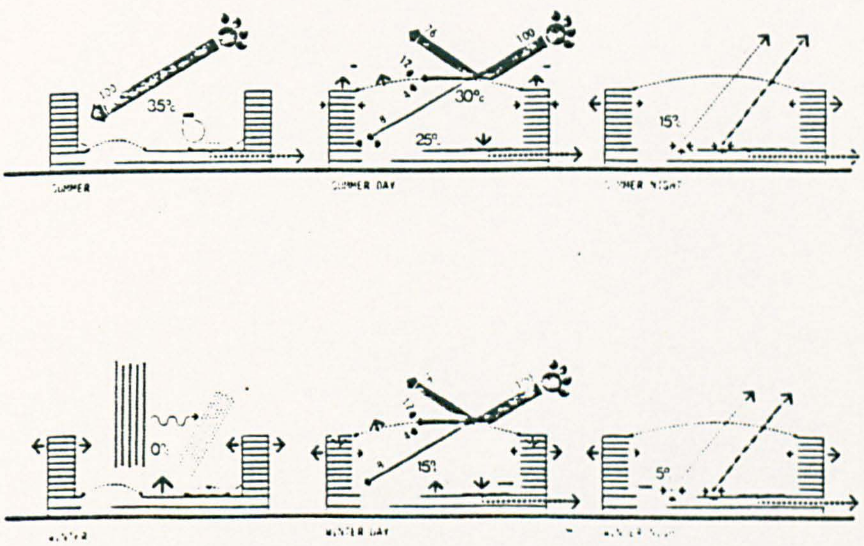


Fig. 9.22. Foster Associates, Hammersmith Centre, London, 1979. In sunny summer weather, the internal temperature is similar to the outdoor shade temperature. The offices are provided with heating and cooling by unitary reversible cycle heat pumps.

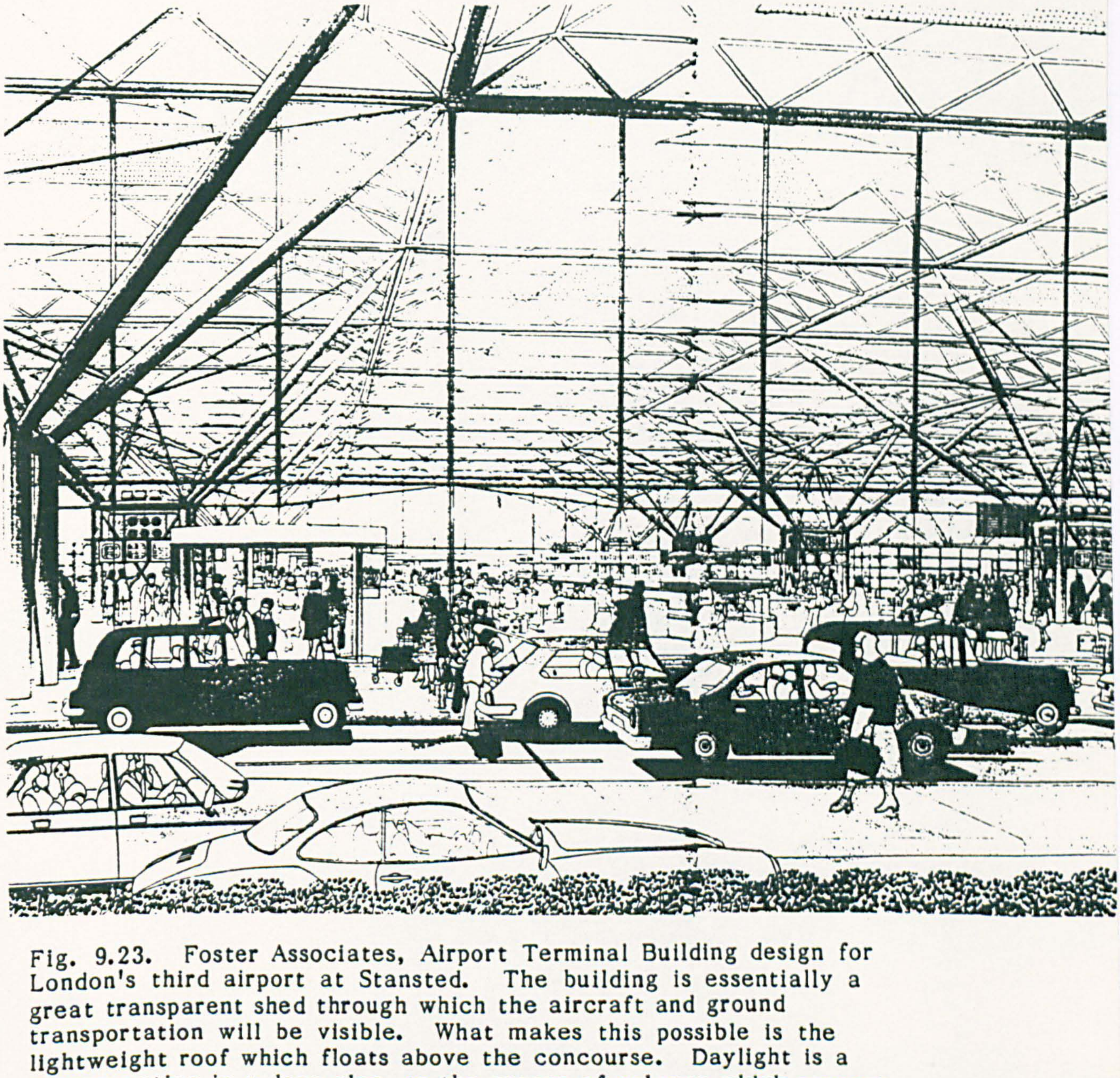


Fig. 9.23. Foster Associates, Airport Terminal Building design for London's third airport at Stansted. The building is essentially a great transparent shed through which the aircraft and ground transportation will be visible. What makes this possible is the lightweight roof which floats above the concourse. Daylight is a preoccupation in a deep plan, so the groups of columns which support the roof, and in which the services are contained, provide heat insulation, absorb sound and at the same time are transparently carved into, so that daylight can be bounced off reflectors and back again to the inside of the ceiling to give a diffused sensation of the outside elements. All services are contained within the groups of columns and so do not obtrude on the domes.

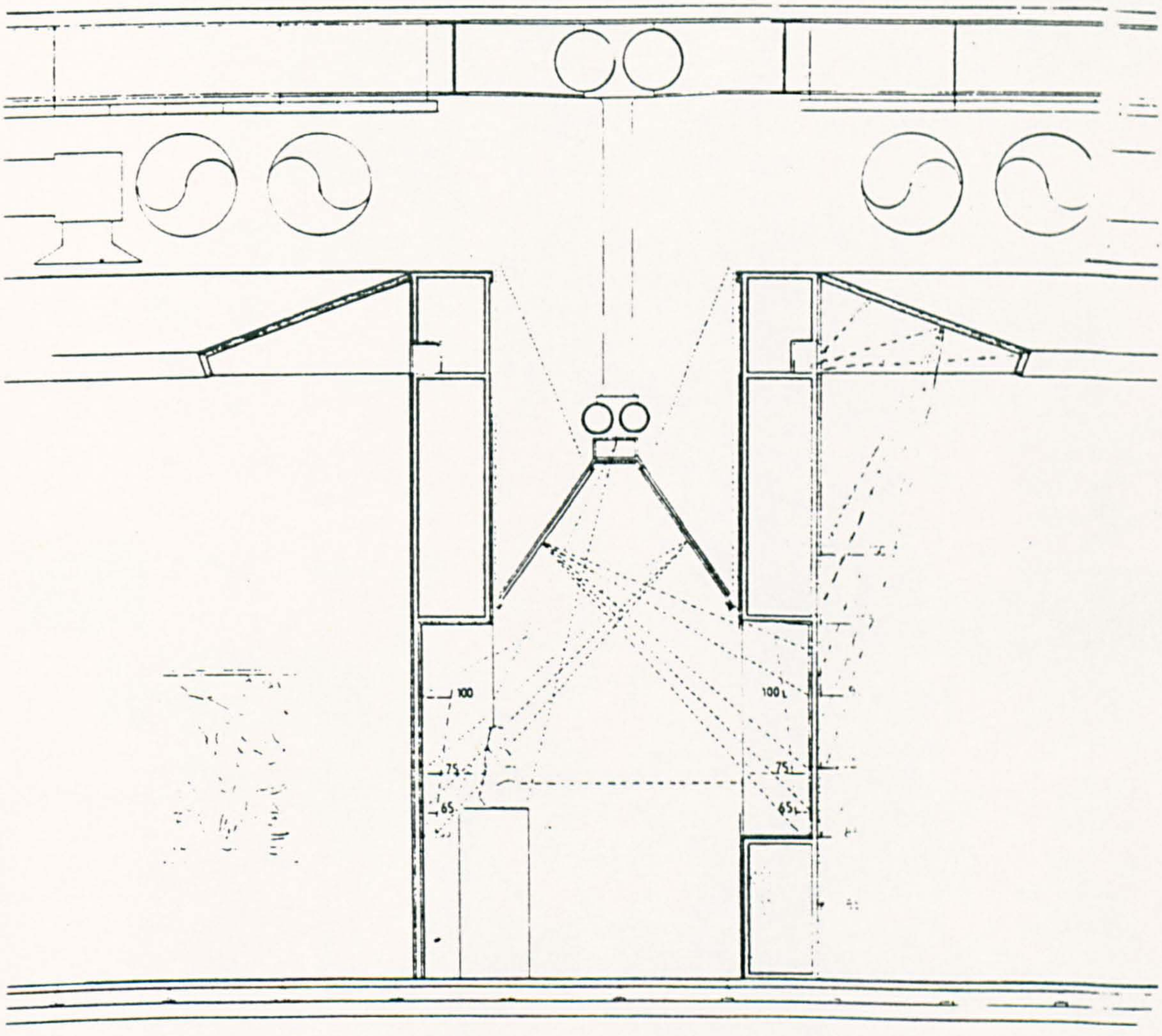


Fig. 9.24. Gae Aulenti, reconstruction of the principal gallery space on the fourth floor of Pompidou Centre. Spatial order and a degree of environmental specificity are introduced into the previously flexible, adaptable, 'soft' interior. The original free plan arrangement has been replaced by a highly structured sequence of rooms which takes the major structural bay of the buildings as its principal determinant. The lighting is incorporated in the walls of the new enclosures, rather than on grids in the ceiling structure as before, and by reflecting off ceiling panels, simulates the lighting quality found in many traditional top-lit galleries.

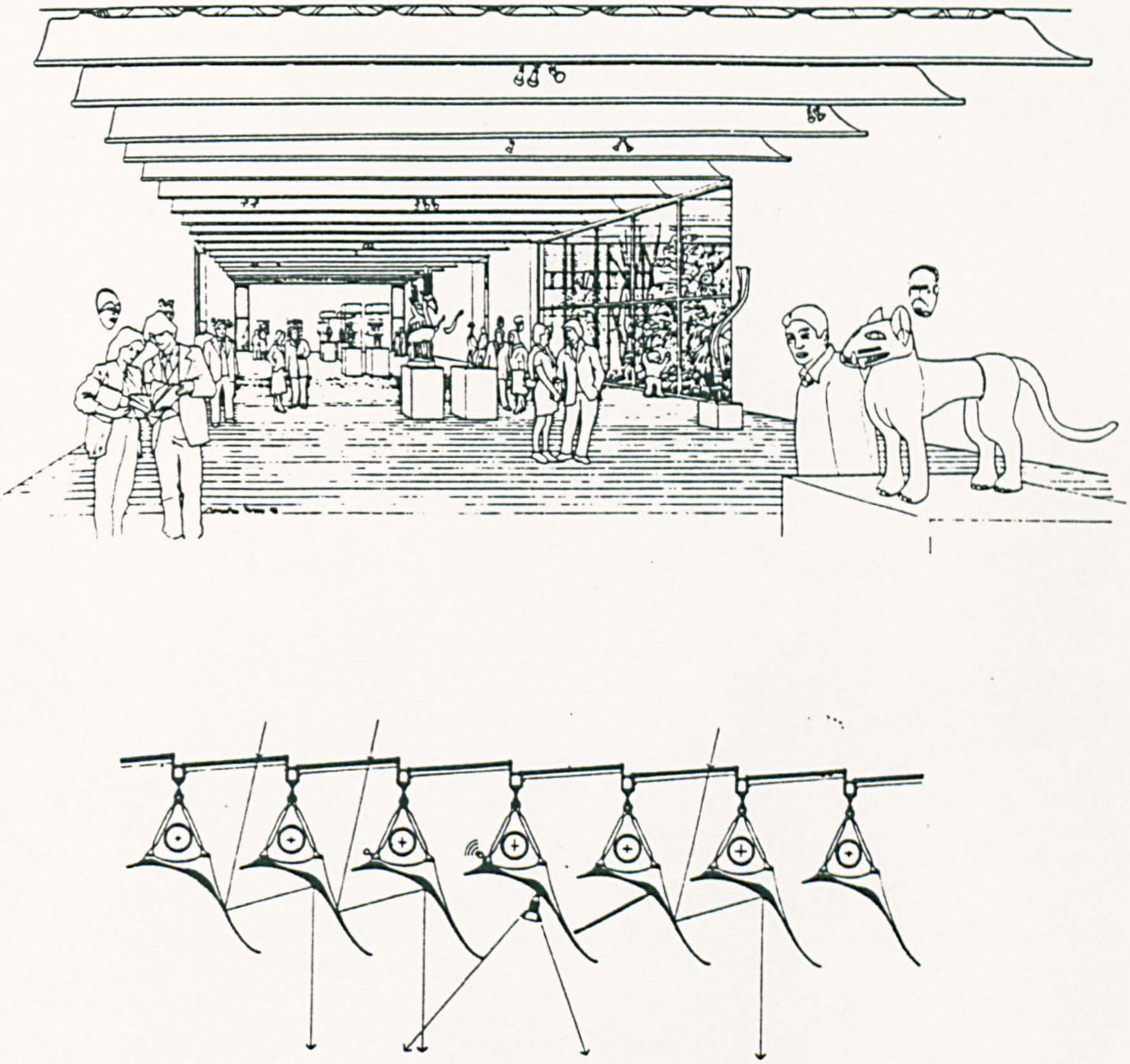


Fig. 9.25. Renzo Piano, recent design for a Houston, Texas Gallery to for the De Menil collection. The ferro-cement and ductile iron roof structure composed of light-baffles acts as a light filter and as a thermal screen. The ferro-cement leaves were manufactured in Britain by specialists in concrete boatbuilding. Above, view of gallery interior. Below, section through the ferro-cement roof structure, showing natural and artificial lighting.

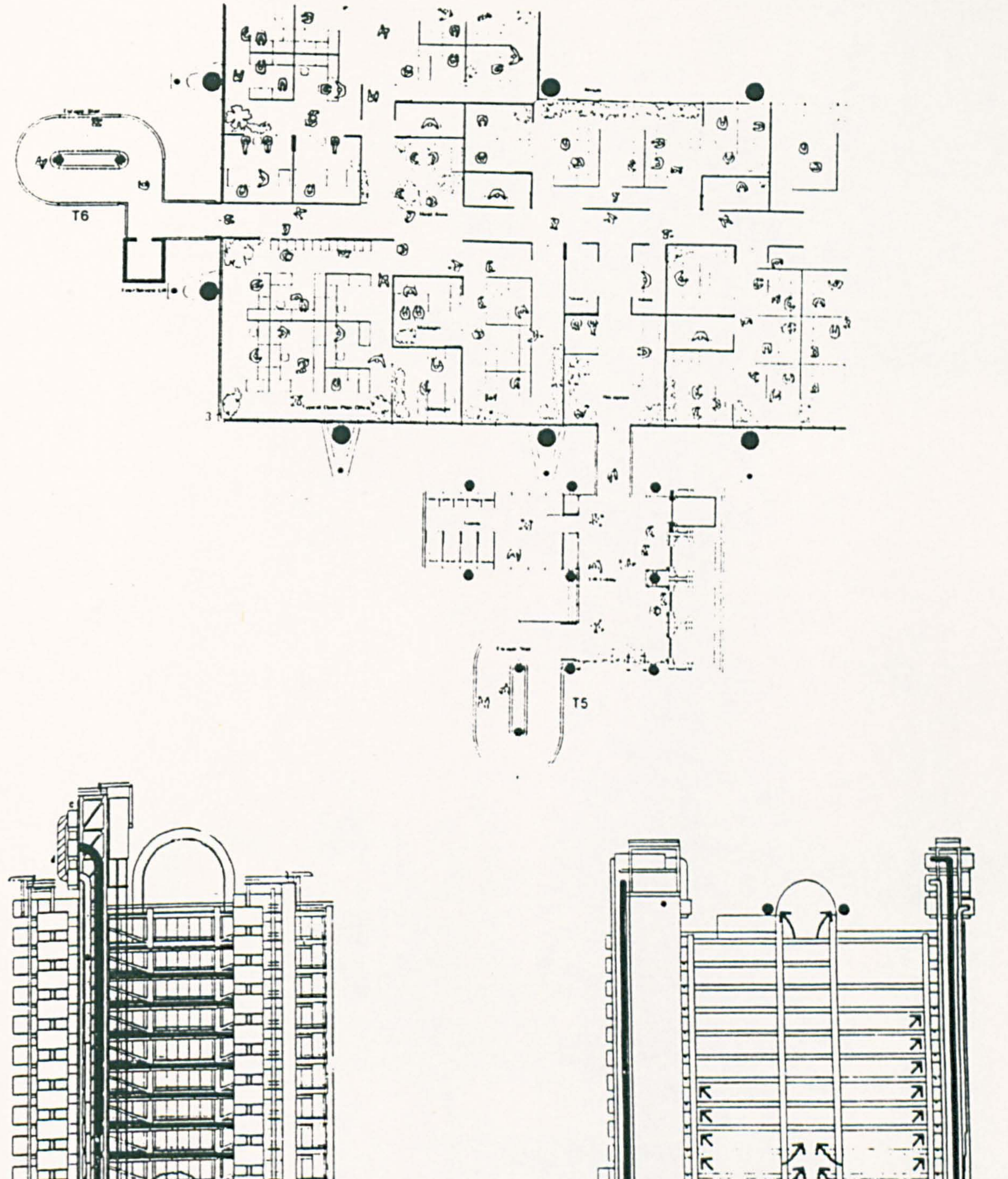


Fig. 9.26. Richard Rogers Partnership, Lloyd's of London building. Above, part plan of typical office floor; below left, section showing (a) supply air; (b) return air; (c)tower air handling plant; (d) recirculating duct. Below right, diagram of extract system hot air drawn up atrium by chimney effect.

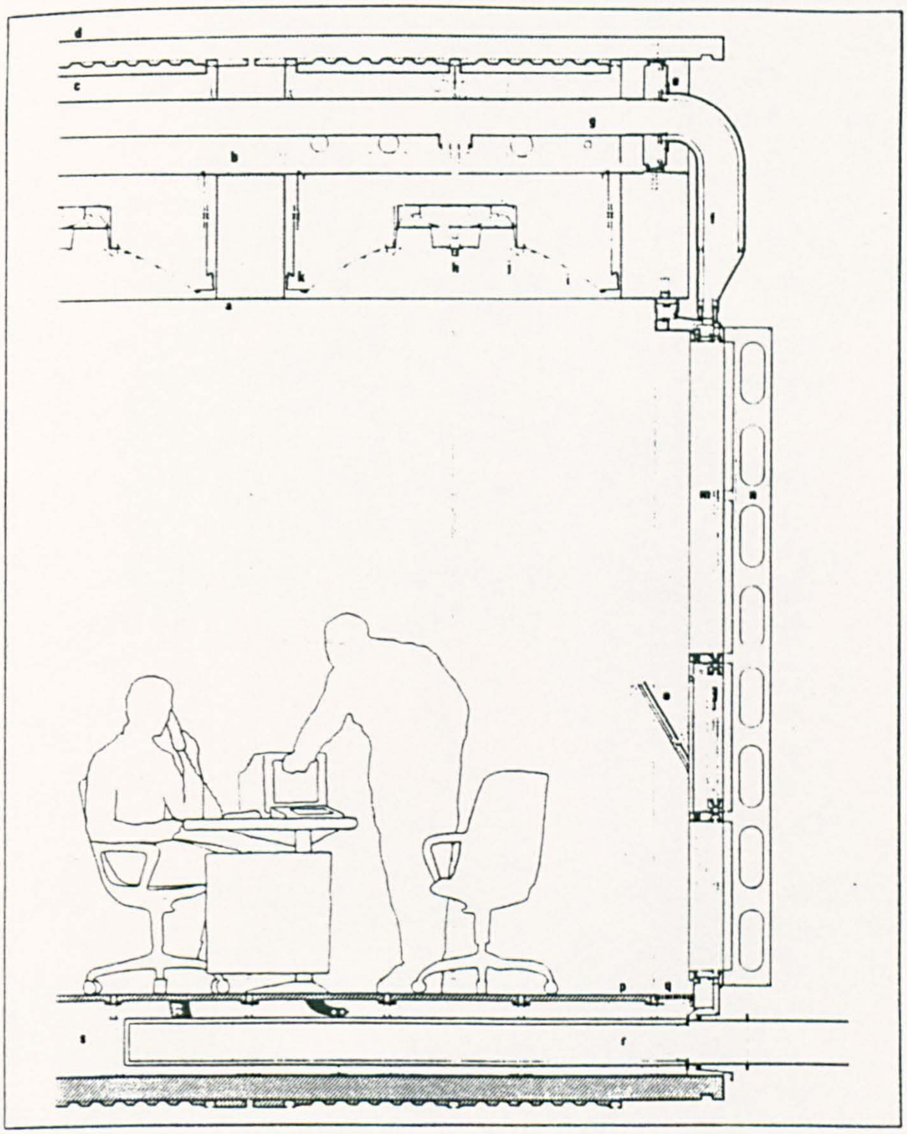


Fig. 9.27. Richard Rogers Partnership, Lloyd's of London building. Section through typical office showing services arrangements in floor and ceiling. a. concrete beam; b. services void; c.steel formwork with acoustic panel; d. 100 mm concrete slab; e. aluminium sandwich panel; f.'fish tail' extract duct; g. extract air through light fittings; h. sprinkler head; i. black luminaire shield; j. aluminium light spill ring; m. aluminium cladding with triple glazing and ventilated cavity; n. aluminium wind bracing fin; o. double glazed openable window; p. steel floor tile on pedestals; q. aluminium air grille; r.insulated supply-air duct; s. floor plenum

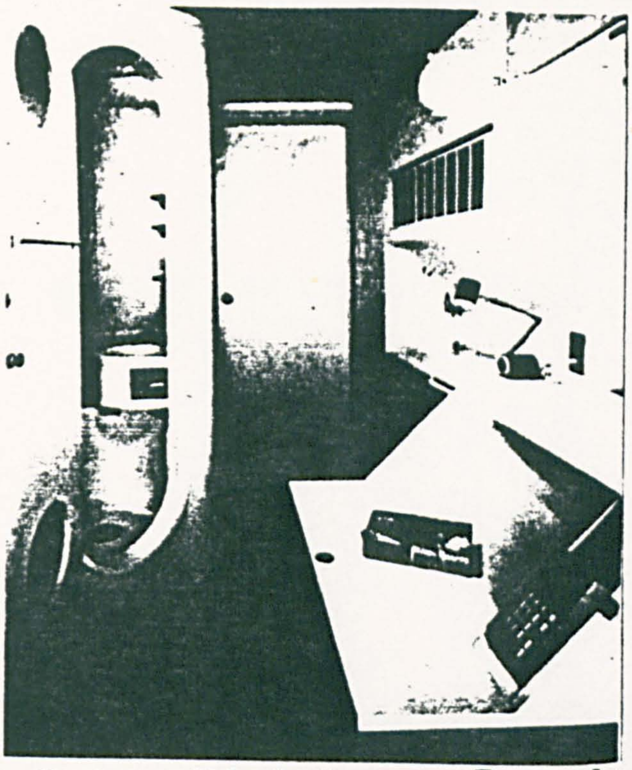


Fig. 9.28. Kisho Kurokawa, Nakagin Apartment Tower, Interior, Tokyo, 1972.

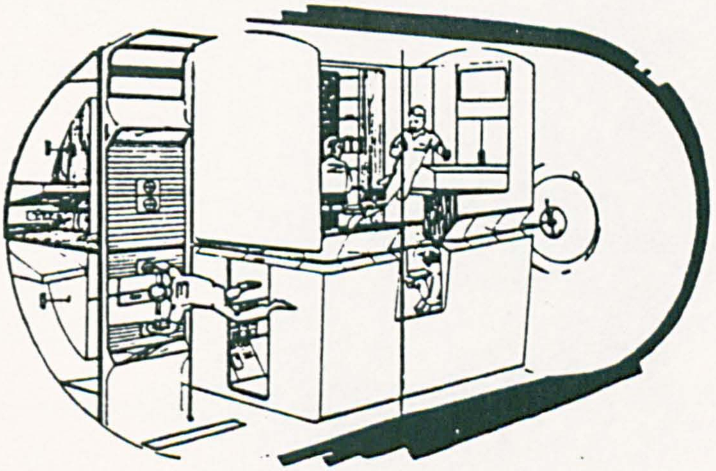


Fig. 9.29. Raymond Loewy, space station design of 1972.

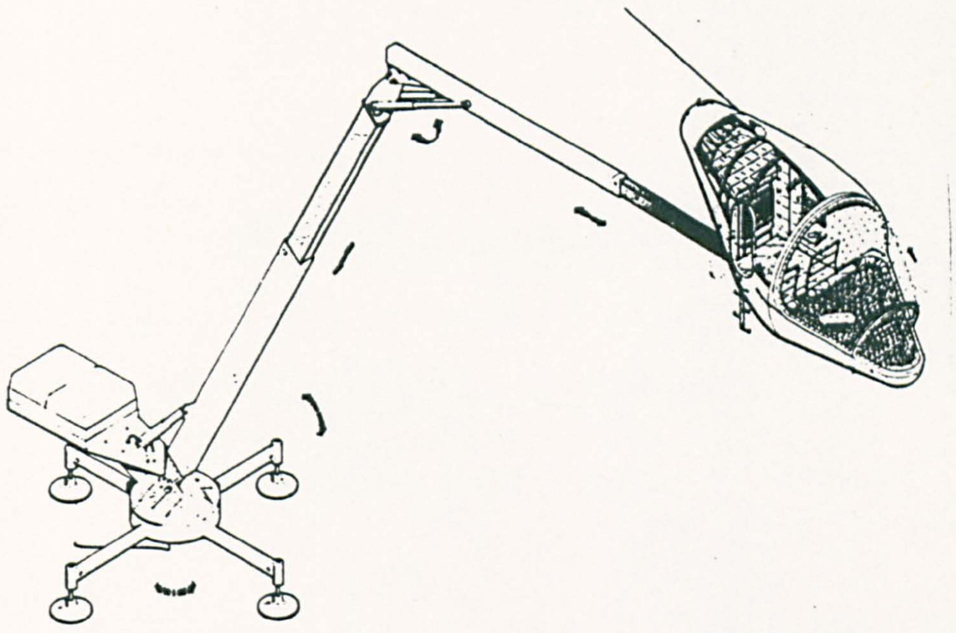


Fig. 9.30. Future Systems, 'Peanut', a kinetic living unit for two people.

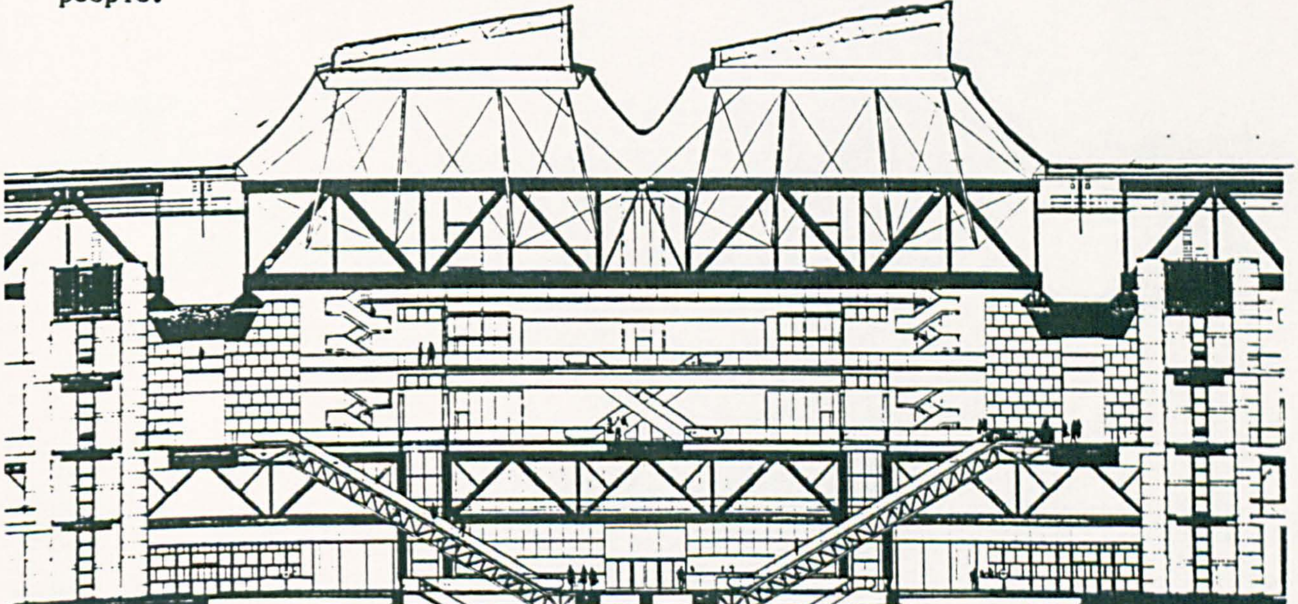


Fig. 9.31. Parc de la Villette, Paris. The biggest and most expensive scientific museum on this planet. Section through central hall showing pedestrian circulation between levels.

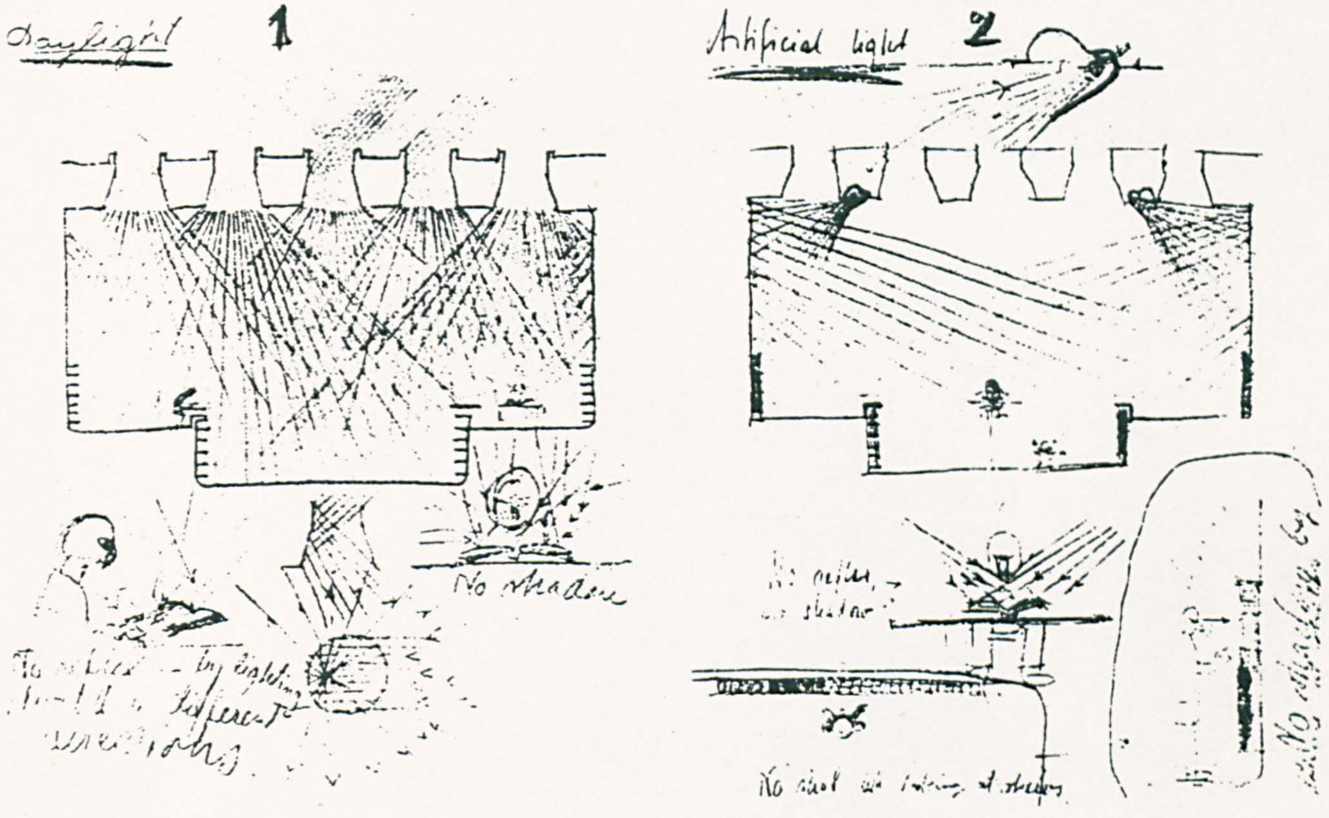


Fig. 9.32. Alvar Aalto. Sketch of relationship of natural lighting and and reading requirements for Viipuri Library.

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